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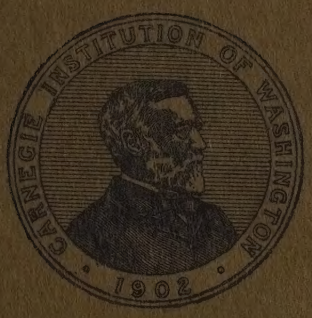
THE VESUVIUS ERUPTION OF 1906

STUDY OF A VOLCANIC CYCLE

BY

FRANK A. PERRET



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WASHINGTON, JULY, 1924

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Dense emission of gas and ash from the greatly enlarged crater, April 10, 1906.

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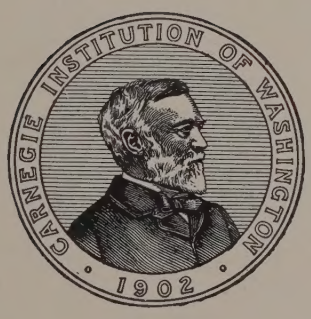
FRANK A. PERRET



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PREFACE.

During the past twenty years Mr. Perret has been a student of volcanic phenomena, living at Naples in the midst of one of the greatest of volcano groups which is anywhere available for study. He was trained as a physicist and is therefore accustomed to apply the precise standards of the physical laboratory to all his observations. It was an accident of ill health which diverted this training and his extraordinary power of observation into the field of volcanology, but there has been no relaxation in the application of those high standards of accuracy with which he had always been accustomed to work. Mr. Perret's appraisal of magnitudes, whether of forces, of dimensions, or of distances, is therefore entitled to be accepted without modification. Accessible magnitudes have been measured and inaccessible magnitudes have been appraised conscientiously and with a background of wide experience.

In 1906 Mr. Perret was privileged to be associated officially with the staff of the Italian Government Observatory, situated on the flank of Vesuvius near the base of the summit cone. He served as honorary assistant to Professor Matteucci, Director of the Laboratory, and with him was a witness of practically all of the phenomena of the last great eruption of Vesuvius in 1906. Professor Matteucci died without preparing any adequate record of this eruption, which undoubtedly was observed under conditions more favorable and probably more intimate than any other known to us. His death was undoubtedly hastened by breathing volcanic ash during these remarkable days when he and Mr. Perret stood guard at the very entrance of Hades.

Professor Mercalli, who was perhaps the most distinguished volcanologist of his time, was also on the ground throughout the period of this eruption, but his untimely death brought to light the fact that he too had failed to leave an adequate record of this overwhelming eruption.

Mr. Perret is therefore the only experienced observer of these phenomena who is now living, and, although he has been very modest about publishing the contents of his notebooks and his wonderful collection of photographs, so long as there was any hope of an appropriate record from official Italian sources, he has at last consented to permit these records to be published.

Mr. Perret became associated with the staff of the Geophysical Laboratory about the time of the outbreak of the Great War. It appeared to me altogether doubtful whether, during this period of strife, and in an atmosphere highly charged with international suspicion, much freedom could be found for the undisturbed observation of volcanoes. In time of war the indispensable camera is an immediate object of suspicion and its use was certain to be limited or forbidden. I accordingly suggested to Mr. Perret that he employ this period of enforced suspension of activity in assembling his notes and photographs of the great eruption of 1906. He consented to do so and a beginning was in fact made, but the entrance

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of the United States into the war, and the distress which surrounded him even earlier than this, were too great a strain upon Mr. Perret's high ideals of patriotism and public service. He entered the service of the American Red Cross and gave to it every ounce of energy at his command for the remainder of the war, while Vesuvius again waited in vain for a historian.

Since then two serious illnesses have intervened to delay the publication still further, but there has been opportunity in the intervals for the observation of the behavior of the mountain during the building-up period between eruptions. This period Mr. Perret believes, and I think his narrative proves, to be equally important with the eruptive phenomena if the mechanism of the volcanic activity is to be thoroughly understood.

Mr. Perret's skill as a photographer, his patience in waiting for favorable opportunities for record, and his daring in approaching violent phenomena are too well known in the volcanological world to need extended comment here, but it may well be said that the illustrations offered represent a more remarkable record of an entire cycle of volcanic activity than any which have been published since those of Pelée in Martinique, by Lacroix.

Even more remarkable are his clear-cut conclusions regarding the mechanism of the gas explosions and their relation to the conduit lavas and the outflowing lava streams. Many of these conclusions are quite novel and will command the attention of every student of volcanic activity. It is to such students that the volume is directly addressed.

In view of the fact that Mr. Perret was in Italy during the latter part of 1923 and the beginning of 1924, when this volume was being prepared for the press, the necessary details of editing the text, arranging the photographs for publication, and reading the proof have been undertaken by Dr. Henry S. Washington, whose efforts to verify and complete the references to the literature of Vesuvius, to secure the necessary maps of the crater and its surroundings, and finally his painstaking attention to details of textual presentation, have contributed greatly to the completeness and homogeneity of the book. A few photographs of the regions devastated by the flow of 1906 and others were also added from the Laboratory files.

ARTHUR L. DAY,
Director, Geophysical Laboratory.

NOTE.—Some remarks, explanations, notes, and other matter additional to Perret's text, inserted by Dr. Washington, are indicated by the initials H. S. W. A bibliography of the most important papers on the 1906 eruption of Vesuvius will be found on page 147. References to papers in this will be given by author's name and number.

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AUTHOR'S NOTE.

In the present volume the writer records his personal observations of the volcano Vesuvius from 1903 to 1921 and presents a detailed account of the great eruption of April 1906, during the course of which he lived upon the mountain and witnessed the various phenomena at close range. The volume, as a whole, should not, however, be considered as constituting a daily record of events at this volcano throughout all these years, as, during that interval of time, outbreaks were studied at Stromboli in 1907, 1912, 1915, and 1919; Etna in 1908 and 1910; Teneriffe in 1909; Kilauea in 1911; Sakurashima in 1914; the Messina earthquake, etc. But as most of these events occurred during the long period of external repose immediately following the great Vesuvian eruption and the beginnings of subsequent crater-filling activity, the record will be found to cover all the important phases, while the position, in time, of the paroxysmal outbreak itself was fortunately such as to include within these eighteen years of observation not only part of the pre-eruption period (Part I of this volume) and the post-eruption repose period (Part III), but also seven years of the present period of renewed activity (Part IV), thus virtually covering a complete Vesuvian cycle.

However much the delay in publishing these details of the great eruption may be criticized, it will at least have strengthened the record by including the important subsequent events and by bringing to bear upon these earlier Vesuvian studies, through later observations at volcanoes of different types, a wider experience and a truer judgment than would otherwise have been the case.

In the earlier portion of the work the reader will look in vain for exact measurements of high temperature, the collection and analysis of gas, seismograms, microphone audition, etc. This regrettable deficiency is due in part to the fact that the writer was then at the very outset of his volcanological career and virtually unprovided with instruments, while the Royal Vesuvian Observatory was, in this latter respect, but little better off. Collection of materials and visual observation, supplemented by a trusty camera, formed the limits of his earlier investigations, the defects of which will be found to be gradually remedied as the work proceeds. It may, at least, be considered cause for congratulation that the needs of that period have now brought about a very different state of things. During the writer's sojourn in Italy the investigation of its active volcanoes has become to a great extent standardized by the general adoption of practical instruments for work in the field.

The general arrangement of this publication consists, first, of a running narrative of the events observed, with frequent reference to a series of appendix notes, in which the various questions raised by the observations are discussed at some length. The narrative of the great eruption is supplemented by an analytical section, where the various phenomena are separately subjected to critical study. Almost every important fact of which mention is made throughout the entire

work forms the subject of an illustration. This photographic documentation constitutes, in itself, a nearly complete record of events. Finally, a series of graphic representations by the writer's diagrammatic system supplements the whole by giving (in addition to an analytic-synthetic presentation of the various phases) a true dynamic perspective which aids in forming a right conception of such widely varying degrees of activity as are comprised within this long series of observations.

Innumerable acknowledgments must perforce be grouped. It is a pleasure to state that the writer's relations with the Italian scientists have uniformly been marked by the utmost cordiality, while courtesy and aid have invariably been extended by all authorities, even throughout the trying and difficult period of the war.

The late Professor Matteucci (former director of the Royal Vesuvian Observatory, in whose company were passed the thrilling days of the great eruption), as well as his immediate successor, the late Professor Giuseppe Mercalli, and both the present incumbent, Professor Ciro Chistoni, and the vice-director, Dr. Alessandro Malladra, with whom were made the writer's descents into the crater, have invariably been prodigal in hospitality and good will.

Thanks are due to the representatives of Messrs. Thomas Cook and Sons for materially facilitating excursions upon the mountain, and to the writer's secretary, Miss Allen, for faithful aid in compilation of the manuscript.

As regards the volcanological research, the greatest credit is due to Mr. Harold A. Ley, of Springfield, Massachusetts, whose loyal and unfailing support has made possible the carrying on of this work during most of these years. Without his encouragement, together with that of Dr. Arthur L. Day, Director of the Carnegie Geophysical Laboratory, it is doubtful whether these investigations could have been continued to the present time.

As has already been stated, the main object of this work is to present a record of the writer's personal observations, which, as will be seen, are mainly from the viewpoint of the physicist. They relate to conditions at this volcano at the times stated. In the study of volcanoes nothing is more pernicious than the habit of generalizing in regard to time, by which an observer states, for example, that a certain crater or other feature "is" thus and thus because he found it so at the moment of his investigation. As Stoppani has well said: "It should be understood that there will never be two persons who, visiting an active volcano, even at an interval of a few days, will find it in the same condition." The conscientious scientist can say little more than: "This have I observed and thus I deduce." Full knowledge is for those who are to come, and the record of the present is for them!

FRANK A. PERRET.

THE VOLCANO VESUVIUS: A GENERAL VIEW.[1]

The fact that Vesuvius is the world's best-known and most fully studied volcano, with a rich bibliography, makes needful here only a brief summary of its fundamental characteristics, with a short account of the period immediately preceding that of the writer's observations.

The original vent was seemingly due to a rifting of the Triassic limestone strata underlying a shallow Eocene sea.[2] A volcanic center of such permanence is generally regarded as situated at the intersection of two fissures that cross at considerable angles. The plausibility of this needs no comment; but, aside from the questionable postulate of such cross-fissures under all the great volcanoes and in view of the known behavior of lateral and eccentric vents originating by simple fissure, the writer is inclined to doubt that an original cross-fissure in the rifted strata is always present. If the volcano originates over a single fracture, the edifice that is built up by the erupted material will first be elongated in the direction of the fissure. This ridge would subsequently (under continued or renewed upthrust from below) tend to break across, forming a second fissure that would localize the vent at its intersection with the first and, by its effusions, tend to render the volcanic structure equal in length and breadth, giving a ground plan which will be more or less nearly quadrilateral. Later, the upper edifice may be superficially fractured in all azimuths, with consequent approach to a circular shape. But it will generally be possible to trace in the basal area (especially in the case of insular volcanoes, where the products of erosion can not accumulate) the structural effects of these two fundamental feeders.

Moreover, the second of these fractures (being superimposed upon the first and deeper fracture) will be the more powerful in influencing later external manifestations, such as the alinement of vents and the migration of the upper conduit, with consequent tendency toward the "Monte Somma formation." Such alinement will, in fact, be generally found in this azimuth, and migration will, more often than not, proceed in the direction of the dip in the syncline—i. e., seaward in coastal volcanoes and toward the deepest sea in insular ones.

Nothing is known regarding the activity of this volcanic vent prior to the first historic eruption in 79 A. D.,[3] except that there succeeded each other long intervals of repose ending in eruptions of a highly explosive type but with the emission of great flows of lava—a condition which continued in modified degree until 1631. Since that date a far more nearly continuous form of activity has prevailed, with diminution of the explosive and effusive factors to more nearly equal proportions, and the normal condition being that with an open conduit, throughout most of the time intervening between great eruptions (p. 61). A result of this change in the

[1] A bibliography of the most important papers on the 1906 eruption is appended on pages 147-148. Papers will be cited in the references by author and number. (H. S. W.)

[2] Cf. Johnston-Lavis 1, p. 35; 2, p. 46.

[3] For an account of the geological history prior to the eruption of 79 A. D., see Johnston-Lavis 1. (H. S. W.)

eruptive habit of the volcano is seen in the virtual elimination of the severe seismic disturbances which formerly afflicted the inhabitants of the surrounding region.

Of even greater interest to the student is the more perfectly revealed element of rhythm in the eruptive process—a cyclical form of activity which clearly indicates the accumulative nature of the normal functions and shows the resulting great eruption as a paroxysmal release of stored energy and material. Although what has been called the Etnean type of eruption—i. e., eccentric outbreaks beyond the limits of the main cone structure—has not been unknown at Vesuvius during the modern era, the normal paroxysm is that represented by the two most recent events, those of 1872 and 1906, which constitute the culminations of periods of lesser activity. (Cf. p. 143 for comparative data.)

The "Somma type" of the volcano resulted from the resumption of activity within the great basin left by the eruption of 79 A. D. and the destruction of the south and west walls. The older encircling ring became known as "Monte Somma," while the ancient name Vesuvius was retained for the later active cone. This has been the cause of the erroneous notion of two separate mountains. The mistake is perpetuated by the guides and railway men on the volcano in their explanations to tourists, although a glance at a map (Plate 1) would seem sufficient to correct the error. The term "Somma type" has, however, come into general use in volcanological terminology to denote this very common partial inclosure of a smaller and later cone by the remaining wall of a more ancient and larger crater. Although the type of activity which built the Somma edifice differed somewhat from that of the present day, yet the writer believes that this difference has been generally exaggerated in the minds of many volcanologists. Mercalli expressed this opinion in conversation with the writer, and both agreed that the remarkable similarity of conic angles was a sufficient proof of this supposition. A glance at the slopes of Somma and the upper Vesuvian cone, as photographed in Fig. 32 and as shown in the scale drawing in Fig. 31, will reveal this virtual identity of angle.

Of great interest to our present study will be a brief review of the active period leading up to the events herein described. The eruption of 1872 left the mountain with the characteristics shown in the comparative data given in Appendix 3 (p. 143), and there followed a period of external repose that lasted for three years. The ensuing period of activity began much like that after the event of 1906 (p. 119), and it followed the normal course of crater-filling with varying but, on the whole, progressively increasing eruptive effects until the occurrence of the first external outflow of lava in 1881. This outflow resulted from a fracturing of the southeast side of the cone—structurally one of its weakest portions—and the outflow was of the sluggish type which characterized all the flows of this period except the last (p. 24). Such outflows tend to build up cupolas around the base of the main cone, thus adding greatly, if inconspicuously, to the bulk of the mountain and filling the valley of the Atrio when the flows occur on that side. This first flow lasted from 1881 to 1883, the second from 1885 to 1886, the third from 1891 to 1894, the fourth from 1895 to 1899, and the fifth from 1903 to 1904. This last brings us to the period of the writer's investigations and is followed, in 1905,

by the first rapid flow of the period (p. 24), which proved to be the precursor of the great outburst of the following year.

There has been thus a marked periodicity in the modern eruptive processes of this volcano, each great eruption releasing energy and material which have accumulated during a more or less prolonged period of lesser activity, in spite of occasional temporary relief through minor outbreaks occurring during that time. Then follows a period of repose, due to exhaustion and obstruction, after which the renewed supply of magma—rising slowly from the depths—reestablishes a vent at the bottom of the crater-basin and a new active period ensues, completing a full cycle. Mercalli called attention to this and published a list of twelve such periods since 1700, each culminating in a paroxysm followed by an interval of inactivity lasting from two to seven years, with three and one-half years as an average.[1]

This succession of minor and major outbreaks has caused some confusion as to what really constitutes an "eruption." In the most literal sense—the one generally used by Italians—any outflow of lava, however tranquil and innocuous, is an eruption, according to which view the above-mentioned slow flows might properly be called the eruptions of 1881, 1885, etc. But the term is more often used to designate any marked or sudden increase of activity, either explosive or effusive, or both, that occurs in the course of a normal active period. This meaning is favored especially by the sensation-loving press, with general restriction by scientists to the culminating paroxysmal phase of the entire period. We speak of the eruptions of 1872 or of 1906, to the exclusion of the minor phases of the preceding periods of activity. Strictly speaking, the volcano is constantly *in eruption* during the whole of this time, but the crescendo-diminuendo effects do not constitute in themselves any new thing, except in the case of an external flow of lava. There is even here no essential difference between flows taking place within or without the crater-basin—though the latter will be more significant to the peasant upon the mountain-side—unless the position and condition of the vent are such as to produce rapid drainage of the conduit, in which case a great eruption may begin.

Vesuvius, from its small size, accessibility, general state of activity, and great diversity of eruptive phenomena, with rich mineralogy, has been called the "cabinet volcano," and, in spite of a natural reaction from the period when it was studied almost to the exclusion of others, the writer believes that it offers the most fruitful field for volcanological investigation. With a type of magma between the extremes of "acid" and "ultra-basic,"[2] and with a structure subject to catastrophic demolition, there are present all the conditions needed for an exceedingly wide range of phenomena, which, as Lacroix has well said, depend mainly upon the physical state of the magma at the time of manifestation. It is thus possible to find here

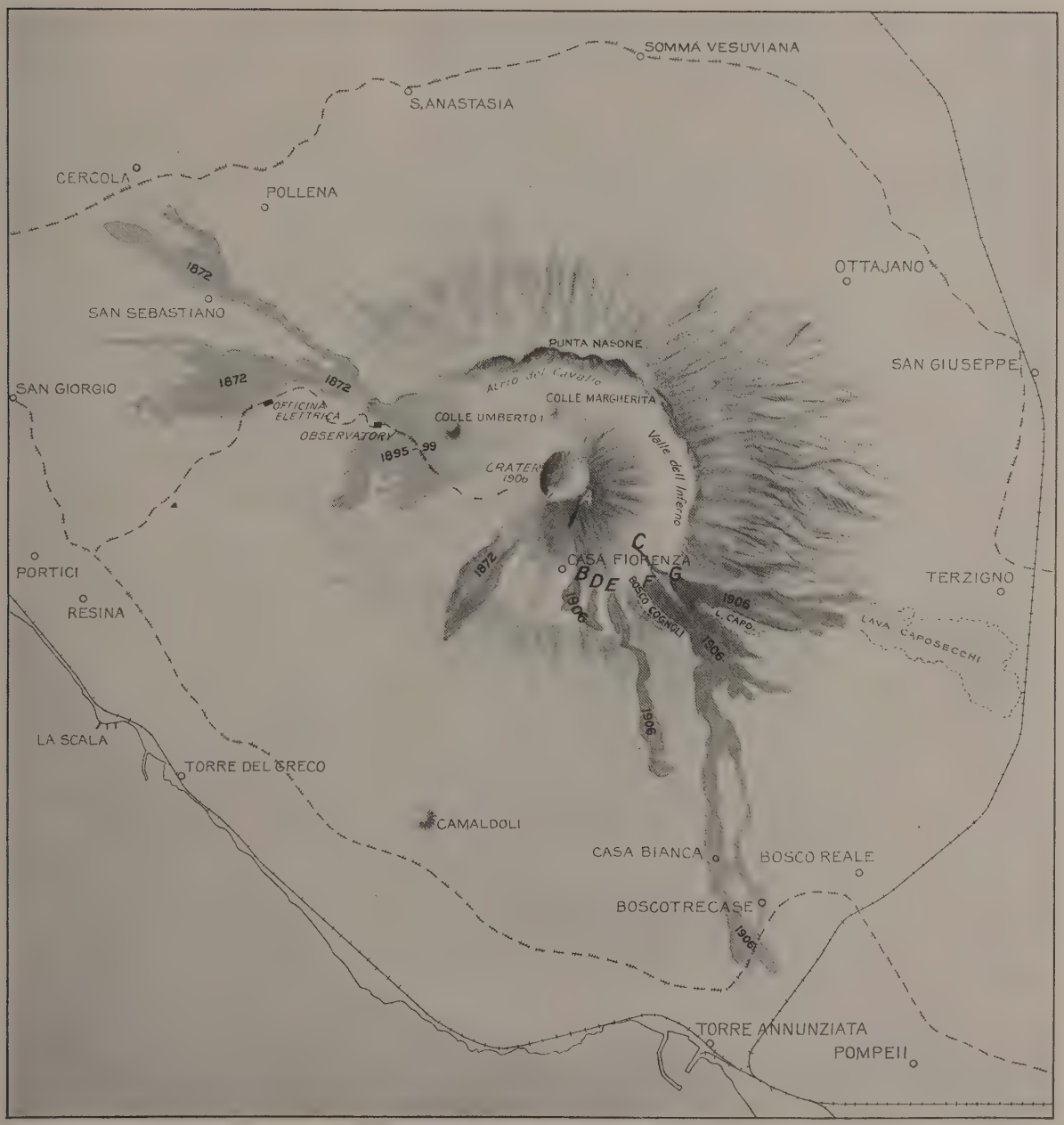
[1] Mercalli (4), p. 208.

[2] The lavas of the central Vesuvian cone are very uniform in most of their characters, being, almost without exception, leucite tephrite or leucite basanite, the chemical differences between the two being very slight. Lacroix has shown that the older lavas of Monte Somma are more variable and that they are rather higher in soda than those of the central cone. The lavas of both Vesuvius and Somma are characterized by the presence of leucite and, chemically, by their very high content in potash, with considerable lime. The group of lavas to which they belong is very rare and such rocks are found at very few volcanoes, scattered somewhat widely over the earth. Vesuvius is the most southerly and only active volcano of a line that extends from Lake Bolsena to near Naples. For petrographic descriptions of the Vesuvian lavas, see H. S. Washington, The Roman comagmatic region, Carnegie Publication No. 57, 1906; Lacroix, Nos. 2, 4a, and 5. (H. S. W.)

an unsurpassed gamut of effects differing only in degree from the extremes of Hawaiian or Krakatoan activity with all intermediate forms.

The writer takes this occasion to call attention to the exceptional opportunities for direct research which this volcano will offer from the present time (1922) for a number of years to come. The great basin of 1906 is filled to within a short distance of the lowest portion of the rim, giving an accessible crater-bottom similar to that of Kilauea, but of far greater degree and different kind of activity, which will be constantly, if irregularly, increasing. It is safe to say that for the next ten years a highly interesting and instructive series of manifestations will here be subject to close-range observation, and the far greater capacity of the 1906 crater-basin, as compared with that of 1872 (p. 143), with a resultant great core of new material filling the upper edifice, makes the future behavior of the volcano a matter of the most intense interest.

It is the writer's fervent hope that his modest study may greatly stimulate investigation at this volcanic center.



Map of Vesuvius. Scale, 1:70,000.

PART I. END OF PRE-ERUPTION PERIOD, 1903-1906.

The writer's acquaintance with Vesuvius dates from the latter part of 1903. Living at that time at Torre del Greco, at the base of the mountain, a good view could be had of the cone with its roundly pointed summit (Fig. 1), and from this distance some interesting observations were made, especially at night.

On several occasions true flames of burning gas were visible, crowning the crater with a halo of pale fire. These flames were faintly luminous, slightly blue or bluish green in color, and were due to fumarolic exhalations consisting, most probably, of burning hydrogen or hydrogen sulphide, and constituting thus the

Fig. 1.—Vesuvius as seen from Torre del Greco in 1903.

somewhat rare phenomenon of flame-emitting fumaroles. At times the tint was yellowish, or "flame color," probably from the presence of sodium. The question naturally arises how such a state of things could be compatible with daily visits of tourists to the crater. In all probability these gases arose mainly from a ring of fumaroles situated on the inner walls and more directly in communication with the volcanic conduit than those upon the upper and external portions of the rim, while the hot blasts due to this gas combustion would be ascribed to hot vapors arising from the pit. In fact, at many places around the crater the ground was unbearably hot, and it was often necessary, at this time, to remain at a considerable distance from the inner edge.

The explosive activity in December 1903 was moderate, with a considerable increase during the month of January 1904. The ejected material consisted quite generally of non-luminous detritus, with occasional projection of a large incandescent mass of fresh lava.

The writer's first visit to the summit was made on January 9, 1904. The crater at that time was divided by a transverse ridge into two distinct basins, unequal both in depth and conformation (Fig. 2). The smaller cavity was without an evident open conduit, but showed instead a number of small pools of very liquid lava emitting whitish vapors and at intervals sending up jets which formed, on a small scale, true lava fountains. This evidence of extreme liquidity of the lava at the top of the magma column, toward the end of an exceptionally long eruptive period, is interesting, because a similar condition prevailed at the beginning of the new active period following the great eruption of 1906.

The larger basin was a much deeper abyss, generally so filled with vapor as to render it impossible to photograph the bottom or even to see it clearly, but the nature of the activity indicated the presence of two vents in whose conduits the lava stood, as a rule, at a low level. This main crater was approximately 150 meters deep. Fairly strong, entirely unrhythmic explosions sent showers of fragments, only in part incandescent, to heights of at least 30 meters above the crater's rim, and so nearly vertical as rarely to fall upon the outside of the cone. Although they were not visible, detritus cones of considerable size must have existed at the crater-bottom as a result of this explosive activity.

The form of the crater, as a whole, was due to collapse following a period of cone-building activity which had culminated in the preceding August, and the basin had approximately the size and the emplacement of the crater of 1900, due, in its turn, to an explosive paroxysm in May of that year.[1] As is generally the case with such types, this crater of collapse showed great inequalities of form, with deep indentations of the rim, overlapping wall-crests, and huge masses projecting inward, with progressive changes due to frequent avalanches of material left in unstable equilibrium (Plate 2). Especially remarkable was a complete eccentric conelet situated upon the rim of the great crater and forming a miniature volcano which emitted vapors constantly, but without projection of scoriæ at this time (Fig. 3).

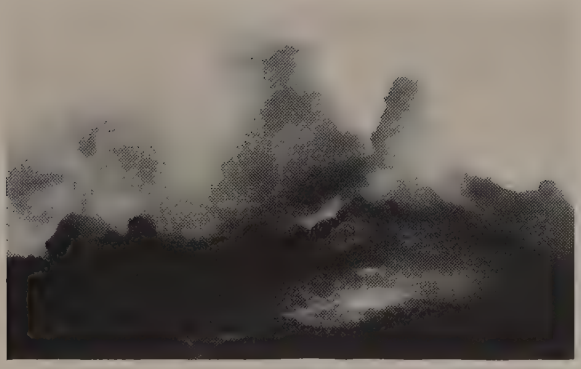
The principal morphological feature of the crater—its division into two basins at different levels—constituted a fine example of the phenomenon (often observed and commented upon) of the maintenance of one lava column at a height very considerably above that of a contiguous one, both proceeding from the same source.

As one skirted the eastern edge of the crater, a view could be had of a lava outflow in the Valle dell'Inferno. This lateral emission was a continuation of that which had followed the cone-building activity during the preceding August, and which had been the cause, by comparatively rapid drainage, of the collapse which formed the present crater. The locality was visited two days later, as described below.

During the entire month of January 1904 the explosive activity of the crater was very considerable, but rarely luminous from a distance, because the lava continued to stand at a low level in the larger basin, the only one that was explosively

[1] Mercalli, *Notizie vesuviane;* Gennaio-Giugno, 1900; Boll. Soc. Sism. Ital., *6*, 1900.

A



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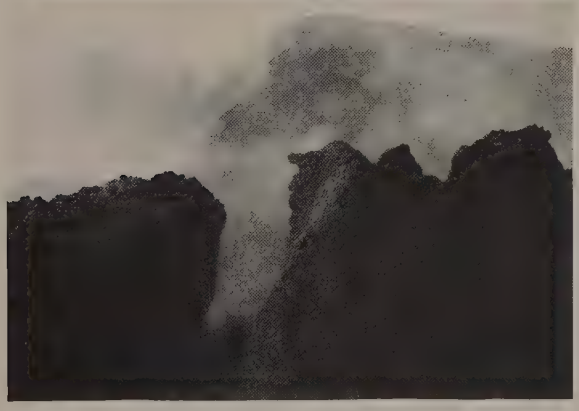

C

Detail of crater-rim, January 1904, showing (A) intensely hot fumarolic area; B, overlapping walls; C, inwardly projecting masses. These were destroyed by the explosive phase of September 1904.

active. During February the activity was considerably lessened, permitting better views of the crater-bottom, and at this time a photograph (Fig. 2) was taken. In March, however, there was a considerable general increase of activity, including an augmented outflow in the Valle dell'Inferno, which sent the lava to the base of Monte Somma.

A first visit to the Valle dell'Inferno, on January 11, 1904, was made by way of the Atrio del Cavallo. Here the lava of the 1891–94 outflow (Colle Margherita), which had reached the walls of Monte Somma, was again separated from these by shrinkage due to cooling, leaving a narrow lane through which one walked more easily than over the rough lava surface, although not without a certain danger of being trapped in case of an avalanche from the all-but-overhanging Somma walls or a stronger explosion than usual from the menacing active crater opposite.

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Fig. 2.—General view of the crater in February 1904. A transverse ridge divides it into two basins.
Fig. 3.—Eccentric conelet, 6 meters high, on the crater-rim, January 1904.

Near the eastern end of the valley the scene of the lava eruption came into view, and the writer was brought into close contact with a perfect manifestation of volcanic activity of the effusive type (Fig. 4). In the midst of a great area of cooling (but still intensely hot) erupted material there stood a small, flat cone some 6 meters in height, from the summit of which there overflowed a fiercely glowing mass whose rate of flow upon the flanks of the cone was approximately 1 meter in four or five seconds (Figs. 5 and 6). At this time the writer was without instruments for the measurement of high temperatures, but he is certain, from subsequent experience, that the material issued from its vent at a temperature between 1,000° and 1,100° C. Much of the surrounding, previously erupted lava was of the aa type, but most of the later-emitted material was pahoehoe, with the usual cascades and lobes, these latter being, as is so often the case, mere shells ready to collapse under the weight of a person and constituting a source of real danger from the still liquid mass within.

This lateral outflow in the Valle dell'Inferno was important, not only as having been a cause of the formation, by collapse, of the crater of that time, as already stated, but also as constituting the last of the "slow flows" which were so characteristic a feature of this eruptive period. As in the former cases, the lava had here been emitted from a number of temporary vents without fixed location, especially after the first great outflow from the base of the main Vesuvian cone, which had apparently consisted of a flood of pahoehoe covering nearly the entire floor of the Valle dell'Inferno.

During the month of September 1904, while the writer was absent from Italy, there occurred an explosive phase which by some was considered the most violent of the entire eruptive period up to that date. This began with the usual cone-building activity, which virtually filled the former crater and culminated explosively during the night of September 23–24. As described to the writer by eye-witnesses,

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Fig. 4.—General view of the aa outflow in the Valle dell'Inferno, January 1904.
Fig. 5.—The summit of the lava conelet; source of the outflow of January 1904.

the explosions formed a brilliant spectacle, and from Naples the ejected incandescent masses could be seen rolling and zigzagging in a peculiar manner down the upper slopes of the cone. The explosions were heard as far as the island of Ischia (Mercalli).[1]

A notable feature was that, coincidentally with the greatly augmented activity of the main crater, the lateral outflow of lava first became locally explosive, then suddenly and completely ceased on the 27th, the cessation being final after an outflow at this point of thirteen months' duration.

At the end of October the terminal conelet, which had formed within the main crater as a result of the explosive activity, collapsed, causing a light shower of ash over the whole region as far as Naples.

On again visiting the summit, in December 1904, the writer found, as a result of the recent violent activity, a profound alteration in the form of the crater, which now consisted of a single deep, funnel-shaped abyss, quite regular in its outline.

[1] Mercalli, *Notizie vesuviane*, 1904; Boll. Soc. Sism. Ital., *11*, 1905.

The number (as well as the activity and temperature) of the fumaroles was greatly reduced and the lava in the main conduit at the crater-bottom stood at so low a level that most of the ejected material consisted of detritus due to the collapse of the crater-walls. Showers of ash were frequent and luminous projections were very rare. The crater was about 100 meters in depth.

Lying all over the upper flank of the cone were lava blocks of a form not seen since that time. These were compact masses, generally in the form of a perfect oval with perpendicular edges and flat sides, although some were roughly triangular in shape. They were as regular in contour and as smooth in surface as though ground in a mill, and were iridescent. The blocks were large and very heavy, but the writer has always regretted not having made an effort to secure samples of these, especially as he has not been able to learn of their having been preserved by

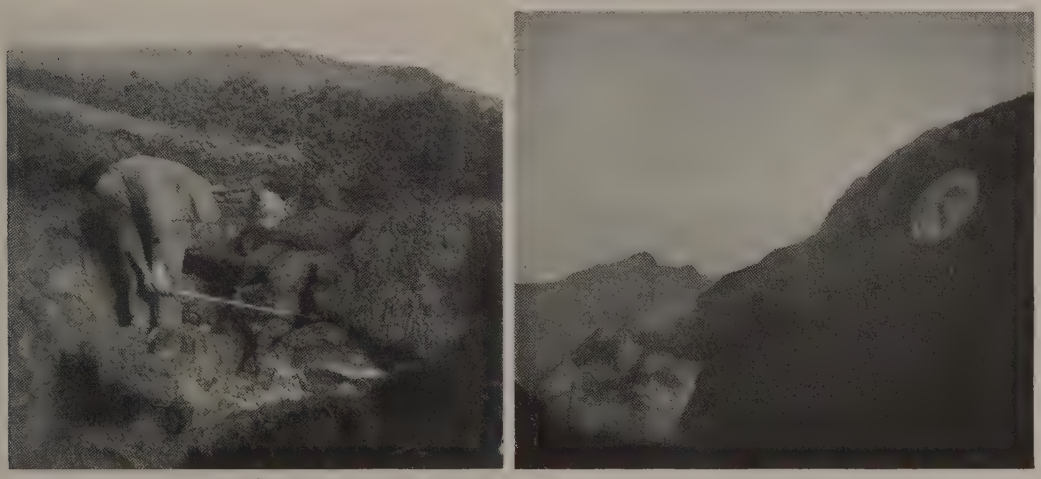

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Fig. 6.—Aa and pahoehoe flows in the Valle dell'Inferno, January 1904.
Fig. 7.—Peculiar lava blocks ejected in September 1904.

others (Fig. 7). They were, of course, soon buried under ash, and in a photograph published by Mercalli, in his *Notizie vesuviane* for 1904, this particular form of projectile does not appear, nor is mention made of its having been observed.[1]

From this time onward the activity of the volcano took the form of a persistent tendency toward the maintenance of a high magma column. The rising lava gradually filled the crater, building up within it the usual terminal conelet of fresh scoriæ, with alternating periods of upgrowth and partial collapse, which were the cause of frequent changes in the visible explosive outbursts. Those which emanated directly from the liquid were brightly luminous and without ash, usually denominated "Strombolian," while, on the other hand, admixture of detritus from the conelet would result in the projection of dark material yielding the type of explosion generally called "Vulcanian."

[1] These lava blocks would appear to have been like the flat, rounded masses that make up the two conelets called I Pizzi, on the north slope of Etna, and found also at Monte Calcarazzi, near Monte Silvestro, on the south. Similar cakes of lava were found by Lacroix (C. R. Acad. Sci., *154*, p. 171, 1912) at the Piton de la Fournaise, on the island of Réunion. (H. S. W.)

Visits to the summit during January, February, and March, 1905, revealed the gradual but variable upgrowth of this conelet within the crater, during which months it remained invisible from without—the mountain appearing, from a convenient point of reference on the crest of Monte Somma, as shown in Fig. 8.

The restricted opening of the conelet's own crater, together with the strong explosive activity prevailing at this time, resulted, notably on March 23, in the formation of many "smoke rings"—circular vortices of ash and vapor, similar, though on a gigantic scale, to those from locomotives, cannon, etc. Although exceedingly beautiful, these were so delicate that they could be photographed only

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Fig. 8.—The Vesuvian cone seen from crest of Monte Somma, March 20, 1905.
Fig. 9.—Same seen from same point on May 22, 1905, showing new terminal conelet.

with great difficulty, and it was not until the Etna eruption of 1910, when many large and robust rings of ash were produced, that the writer succeeded in obtaining good views of this phenomenon.[1]

On April 19, 1905, after an interval of four days, during which time the summit of the mountain had been hidden from view by a severe snow-storm, through which the ruddy glow of intense explosive activity was translucently visible in wondrous contrast with numerous blue-white flashes of lightning, the inner conelet was seen for the first time emerging above the rim of the main crater, and the terminal activity could thus be observed from a distance.

The conelet continued to increase in height, though with many vicissitudes, sometimes showing the liquid lava at full level with its crater and even overflowing

[1] Perret (3). [Such rings were observed at Stromboli by Bylandt Palsterkamp (*Théories des Volcans*, Paris, 1825, *2*, 343, and Plate 14), and at Etna, in 1838 and 1843, by Sartorius von Waltershausen (*Der Etna*, Leipzig, 1880, *1*, pp. 76 and 119). The latter says that the rings began as rotating globes that gradually opened out. H. S. W.]

through some temporary cleft in the rim. The explosions were often so powerful as to send magnificent sheaves of liquid to heights of several hundred meters. The liquid in falling rendered the conelet, and even the upper portion of the main cone, brightly incandescent for several minutes. Growing thus by accretion, this terminal structure reached its greatest height on May 22, 1905, when Vesuvius attained the unprecedented altitude of 1,335 meters (Fig. 9).

The smaller cone, however, was never built up to the point of completely filling and obliterating the outline of the main crater, the lip of which remained, in nearly all azimuths, at a slight elevation above the intersection with the base of the terminal structure, as shown in the photograph, Fig. 10.

With such conditions as these, in a volcano of this type, a great eruption surely impended. The great height of the lava column, with the consequently strong pressure upon the walls of its conduit; the maintenance of the liquid at a high

Fig. 10.—Contact between terminal conelet (left) and rim of main crater.

temperature by active gas conduction and reaction, with consequent fluxing power; the restriction of the vent to the tiny dimensions of the terminal craterlet, with resulting increase and accumulation of gas-tension in the lava column—these factors could not fail, sooner or later (given continual intensification of the conditions) to bring about eruption, by the most natural means, in a volcano of this type—that is, perforation of its containing-walls and rapid drainage of the conduit, thus relieving the pressure upon the lower surcharged magma and initiating a paroxysmal gaseous outburst. This would then continue through progressively powerful phases up to the point of exhaustion of the accumulated material.

Such a culmination, at this time seemingly imminent, was postponed—and for a period of not less than ten months—by an unlooked-for phenomenon which acted as a safety-valve, diminishing to some extent the tension resulting from the extreme conditions outlined above and providing an outlet for some of the new lava.

Immediately following a period of intense explosive activity, alternating with days of perfect calm, during which the lava remained quiet but intensely hot and

liquid and almost level with the orifice of its crater, the main cone was fissured on the northwest side for a short distance below the summit and approximately down to the site of the old crater of 1872.

The writer was fortunately an eye-witness of this outburst. While watching the mountain from Naples at 6^h30^m in the afternoon of May 27, 1905, a cloud of white vapor was seen to shoot horizontally from the side of the cone at some distance below the terminal vent. In a few moments there appeared through the vapors the red glare of lava, which later, as the cloud lifted, was seen to be descending the cone in a brilliant stream of fire. A second vent soon opened, followed by a third, all simultaneously in action in spite of a considerable difference of level. Soon after the outflow of lava began the activity of the crater suddenly ceased, with partial collapse of the terminal conelet, but the explosions soon recommenced, with ejection of the collapsed material (Fig. 11).

Fig. 11.—Night view of lava-flows from the three principal vents on the northwest flank of the cone, about June 1, 1905; Observatory on the left.

On ascending the mountain the following day it was found that the two principal streams of lava had reached the base of the main cone, where it was possible to ascend the crest of a medial pseudo-moraine (itself in constant motion) to a considerable elevation directly between the two streams. Here the degree of incandescence could be studied to great advantage as it changed from a deep garnet by day, through bright red as twilight came on, to a clear golden yellow by night.

It should be remembered that this was the first rapid outflow of any importance in the entire eruptive period, and its qualities were in strong contrast with the slow upwellings of lava which had formed the various cupolas around the base of the main cone during the previous years.

The lava at its source was flowing at a rate of 60 centimeters per second near the vent, which velocity naturally became less at longer distances, but as the slope upon which it flowed was steep for the greater part of the descent, the rate of flow remained high for a lava of this type.

On the following and several succeeding days up to June 2, 1905, the character of the lava emission from these vents varied according as the central lava column remained at approximately the same level as the vent or rose considerably above it. In the former case the outflow was quiet, but a higher lava column invariably resulted in light explosive effects at the eruptive mouths, with emission of gas at high pressure. At the upper vent, on June 2, a fiercely blowing driblet-cone emitted sulphur dioxide in such quantities that attempts to obtain a photograph failed, the only good viewpoint being to leeward, and it was not until some time later, when the emission of gas had ceased, that a picture could be made (Fig. 12). A similar cone formed at the lower vent.

Fig. 12.—Driblet cone of upper vent of northwest subterminal flows, June 1905.

From beneath the base of this driblet-cone the lava issued in a full-flowing stream, exceedingly liquid at the point of emission, but rapidly solidifying at the surface, amid the escape of vapors. This was the beginning of a process of scoria formation that developed progressively during the flow. Even near its vent the lava ran in a sort of raised trough formed of the congealed mass (Fig. 13), and it was here that the writer first fully realized the need of effective instruments for measuring high temperatures, apparatus for gas-collection, etc., the lack of which during this period has already been deplored (Fig. 14).

Such subterminal outflows, when rapid, generally form a type intermediate between the extremes of aa and pahoehoe, the main body of material being compact, homogeneous, and continuous even upon a slope, with but superficial formation of scoria. The type must therefore be classed as aa, but abnormal in having a relatively large unbroken central mass, as will be evident from an inspection of Fig. 15. The same general conditions were present in the lava eruption of Stromboli in 1915.[1]

During the last days of June 1905 the lava ceased flowing from the uppermost vent, and from this time the entire outflow was limited to the lower mouth, situated at scarcely more than 100 meters north of the upper station of the funicular railway and at approximately the same altitude. At this main vent the fracture in the walls of the cone was open at the surface, extending irregularly upward toward the summit, as shown in Fig. 16, and there can be no doubt that the lava reached the vent through a tunnel whose sides were formed by the walls of a fissure in the

[1] F. A. Perret, *The Lava Eruption of Stromboli, summer–autumn 1915*. Amer. Jour. Sci., *42*, 443, 1916.

cone.[1] It is important to bear in mind, in view of the relationship of these rapid flows of lava to the causes of the great eruption, that although they have rightly been designated "subterminal" as regards the outer form of the mountain, in reality they were but *overflows* from the upper portion of the lava column within

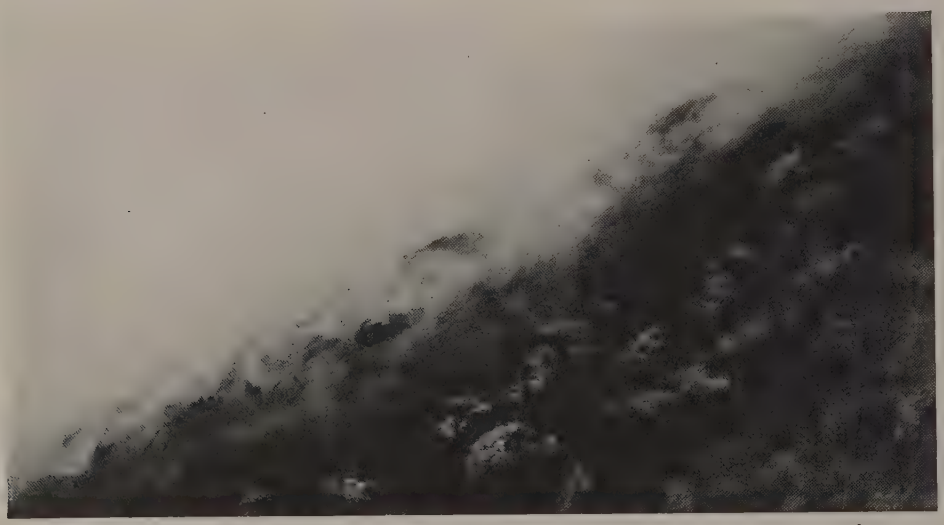

Fig. 13.—Northwest subterminal lava-flow just below its vent; rate of flow, 40 meters per minute.

Fig. 14.—Liquid lava (left) flowing from the source of main subterminal flow.

the cone and therefore, although copious, could never materially reduce the level of the lava inside the mountain and thus bring about the paroxysmal reaction.

The interesting point as to how the lava can continue to overflow from the upper extremity of a magma column, whereas the same column would not neces-

[1] [Von Waltershausen seems to have witnessed the filling of such a fissure in the crater-wall of Etna in 1838 (*Der Etna*, Leipzig, 1880, *1*, 72. H. S. W.]

sarily increase in height if no outflow took place, may be explained by the condition of balance that results from an equilibrium between the upthrust from below and gravity, with atmospheric pressure and gas vesiculation as subsidiary factors. The failure to rise to higher levels is not due to any limitation in the supply of material; when overflow occurs there is simply a slight disturbance of isostatic equilibrium, which is quickly restored by the rising of fresh material from below.

An important result of this circulation due to overflow is the thermal increment from the rise of fresh magma charged with hot gas. It was in fact at this time, and at a point somewhat to the southward of the main vent and at a higher level, that

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Fig. 15.—Main lava stream descending the northwest flank of the cone, seen from Colle Umberto I. Note the progressive diminution of vapor.

Fig. 16.—A fracture that extends upward from subterminal vent to crater-rim.

the writer was first privileged to witness the phenomenon of re-fusion. He was standing with a group of students upon the hard lava surface of the cone when this gradually increased in temperature until the heat underfoot was unbearable. On moving away, it was observed that a round area some 2 meters in diameter was becoming incandescent in full daylight, and this began to swell upward until, without a fracture, the material reached the point of complete fusion and a small, ephemeral lava stream started flowing down the slope. There was no explosive emission of gas, the fusion resulting from superheated lava beneath the surface.[1]

[1] Dr. G. W. Morey has suggested to the writer that, inasmuch as gas at high pressures and high temperatures expanding to low pressure through a porous plug becomes warmer, this might explain the phenomenon, provided the ground were sufficiently porous. Whether the fusion resulted in this manner or was due to simple conduction, it is evident that superheated lava was brought close to the surface and was possibly localized through intersecting vertical and horizontal fissures.

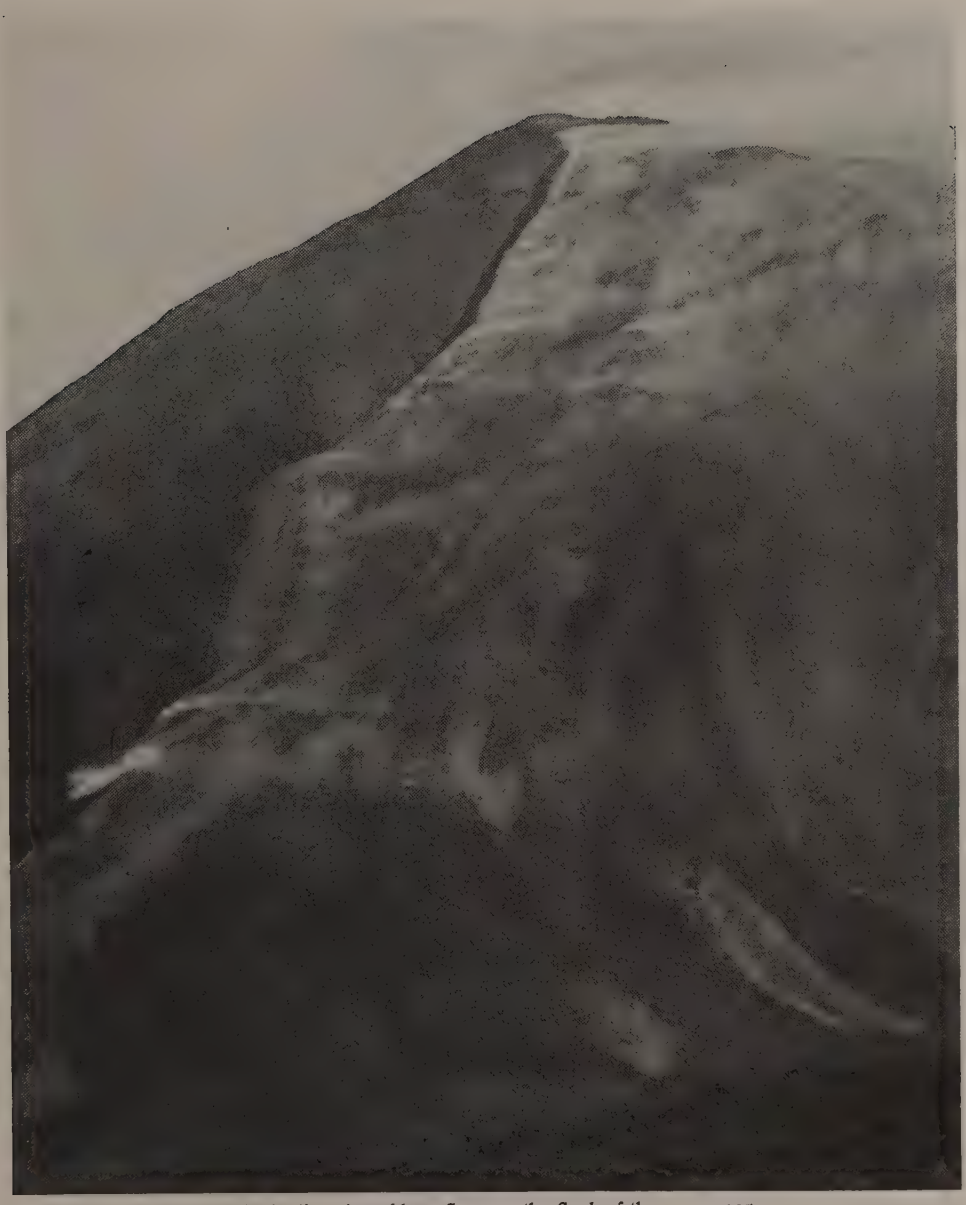
An example of the re-fusion of hardened lava by the superheating of a fresh stream is shown in Plate 22 (A and B).

The enormous importance of this power rapidly to remelt and absorb old solidified material is discussed elsewhere, and there can be no doubt that the perforation of the main cone which finally started the great eruption was, in

Fig. 17.—Ends of lava streams at base of cone.

part at least, due to fusion of its walls during this period of superheated conditions in the upper portions of the magma column.

During the remainder of the year 1905 the flowing lava upon the northwest flank of the cone formed a brilliant spectacle of great variety, due to the continually changing direction, with subdivision and meandering, of the brightly glowing streams (Fig. 11). The continual deviation was caused by accumulation at some



Multiple diversion of lava-flows on the flank of the cone, 1905.

given point, with consequent flowing down to one side or the other, and by this process there resulted—as is usual in a flow from a single source on a steeply sloping cone—a fan of congealed lava (Plate 3), whose base was fringed with stream terminals frozen *in situ* through failure of the supply by deflection above (Fig. 17). The lava could be seen from below issuing from its vent, highly charged with vapor whose emission gradually ceased with the progress of the flow (Fig. 15).

Superficial tunnels were formed frequently—that is, a hard crust within which the lava flowed for some distance, only to burst forth in full brilliance farther down the slope. The explosive conditions at the crater also varied incessantly during the last half of the year, and in general the greater outpourings of lava were synchronous with the explosive maxima. But both phenomena—if we except one strong deviation of the lava southward early in September 1905, which cut the line

Fig. 18.—Rapid outflow of lava on February 2, 1906.

of the Vesuvian railway—were limited to unimportant augmentations and diminutions of the eruptive activity, which it would be tedious and useless to chronicle.

Realizing, however, that important events were impending, the writer accepted the post of "Honorary Assistant to the Royal Observatory," offered him by the director, Dr. R. V. Matteucci, and so was privileged to observe at close range the phenomena of the great eruption.

We thus come to the eventful year 1906!

It is now easy for one looking back on this period to see that the continued resistance of the main cone throughout this long attack upon its integrity presaged an eventual fracturing in some part other than the northwest sector, where—in spite of these terminal lesions and the proximity of the profound, but probably sealed, fissure of 1872 (Plate 11)—the containing-walls were probably more solid than at any other points excepting possibly the west and south. Such, however, was not our opinion at the time, especially when, during the first days of February, the eruptive conditions, both explosive and effusive, assumed an intensity which seemed to be a prelude to the great event we had been so long expecting. Already, on January 31, 1906, from the crest of Monte Somma the crater was seen to be in a

state of suppressed activity which can perhaps best be described as an ugly mood, and on February 2, 1906, the outflow of lava increased to full, free-flowing streams, clear and liquid throughout their entire length, as shown in Fig. 18.

For a day or two the material accumulated at the base of the cone, with a lake of considerable depth between the Colle Umberto I and Monte Somma, but on

Fig. 19.—A live lava-flow between two cooled ridges, February 7, 1906.

Fig. 20.—Head of advancing lava-flow.

February 4 the lava started southward upon a work of destruction at an average speed of 12 meters per hour, threatening the Vesuvian railway between the Observatory and the main cone. At 6^h30^m p. m. the lava reached the rails, crossing at a point where the line made a double turn, thus cutting it in three places at one stroke. On February 6 a branch stream started toward another portion of the

line, which it crossed on the morning of February 7, when the eruptive phase culminated in paroxysmal conditions at the main crater, with long, roaring explosions and the emission of clouds of ash, which, with the advance of the glowing and hissing tongues of lava, formed a manifestation of no inconsiderable volcanic activity (Figs. 19, 20, 21, 22, and 23). Still the walls of the great cone held fast.

Again the eruptive forces subsided, with continual variations, until the vernal equinox, when a powerful phase of purely "Strombolian" activity began with lofty jets of wholly liquid, intensely brilliant lava accompanied by the well-known salmon-

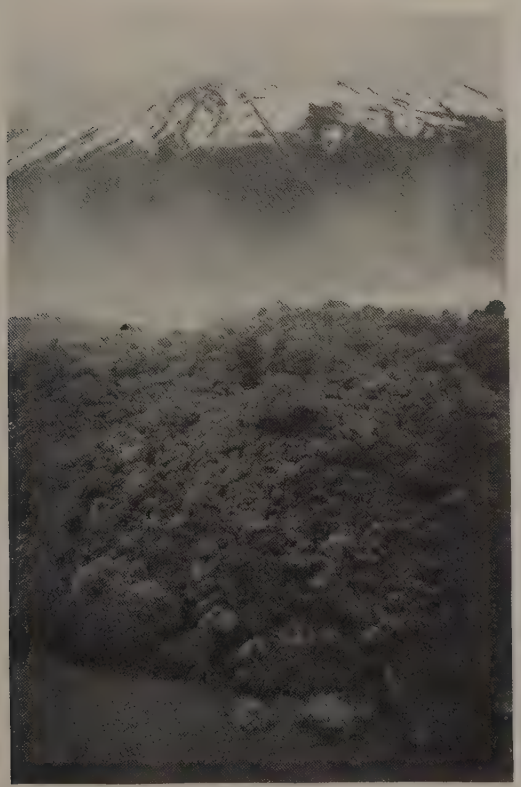


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Fig. 21.—West branch of aa lava-flow; summit covered with snow. February 7, 1906.
Fig. 22.—Lava-flow descending northwest flank of cone, February 7, 1906; strong explosive conditions at crater.

colored vapors. From Naples it could be seen that some of the jets were thrown out laterally and even almost horizontally, indicating that the lava stood nearly level with the crater-rim, and on visiting the summit on February 16, when the explosive action had for the moment ceased, this was found to be the case. The effusive phenomena also were increased by the opening of a new lava-vent near the other one, with rapid outflow of fresh material.

The writer fully agrees with a remark of Mercalli to the effect that in volcanoes of this type a column of lava maintained at a great height, intensely hot and liquid

(no matter how tranquilly it may comport itself for a time), constitutes a source of potential activity.

During this visit to Vesuvius, the writer, at night in bed, thought he could hear a continuous buzzing sound which seemed to come from below. When he set his upper teeth against the iron bedstead he heard the sound more positively, and there

Fig. 23.—The Vesuvian railway covered with lava from the northwest subterminal vents. Note absence of snow near the lava outflow. February 7, 1906.

could be no doubt of its objective existence. Had he then possessed the microphone apparatus since developed, the revelation of this premonitory symptom of the great eruption would have been more positive and definite.

Nine days later, dense, dark clouds of quite unusual aspect, issuing intermittently from the crater, clearly indicated a breaking down not only of the terminal conelet, but also of the walls of the cone itself, and there could be no further doubt that the long pre-eruptive period had reached its culmination.

View of Vesuvius from Hotel Eremo. Observatory on left, "chalet" on right, funicular railway near right slope of cone.
Photograph by A. L. Day, June 1914.

PART II. THE GREAT ERUPTION, APRIL 1906.

NARRATIVE.

THE LUMINOUS, LIQUID-LAVA PHASE.

Part I of this volume contains descriptions of the various phases of activity that led up to the great event which we are now to consider, the last of those phases having been the subterminal outflow of lava that began on May 27, 1905, which continued uninterruptedly for more than ten months. There has been some tendency to consider this phenomenon as a part of the culminating phase of the great eruption. Thus, Mercalli[1] writes: "The great eruption of last April is but the final crisis of a subterminal lava-outflow begun the evening of May 27, 1905." And Matteucci[2] states: "In April 1906 occurred the final period of the eruption begun May 27, 1905, with a lava-outflow on the northwest sector." De Luise[3] goes so far as to say: "The eruptive period, which had its epilogue in the conflagration of last year, began May 27, 1905, with a lava-outflow on the west-northwest sector of the cone."

While regretting the adoption of a polemical attitude thus early in this work—and that in regard to a matter which by some may be considered trivial—the writer feels bound, nevertheless, to insist upon the advisability of clearly distinguishing between the great eruption itself and all or any of the preceding manifestations, which, in comparison, are but steps marking the crests on a curve of relatively moderate activity. The final catastrophic paroxysm, in its rapid disengagement of accumulated, concentrated energy, so transcends all these single episodes of the entire active period that to consider even this last and most important of them as forming part of the great outburst must offend that sense of proportion which it is most important to preserve in the study of a complete Vesuvian cycle. Besides, from their very nature and functions, these outflows—when, as in the cases considered, they fail to disrupt the main cone—so far from constituting part of the great eruption, are really the very antithesis of this, inasmuch as by relieving the accumulation they actually postpone, and thus for a time prevent, its consummation.

In a sense, the entire active period forms one manifestation having many phases of varying importance, and of these the subterminal lava-flow was the penultimate. It holds among its fellow episodes the preeminence of ushering in the great event, but it was not that event or a part of it. The distinction is clear and should be maintained.

We come, then, to the morning of April 4, 1906. From Naples the usual white vapor was seen issuing from the crater with a subtly but decidedly unusual aspect impossible to describe. As the skilled physician sees in the patient a significant change which to other eyes is not revealed, so the volcanologist, observing the crater on this day, saw there the signature of a new power. And soon into the neatly

[1] G. Mercalli (3), p. 5. [2] R. V. Matteucci (1). [3] L. de Luise (1).

contoured vapor column there began to be injected masses of dark ash (Fig. 24) which continued during the day with increasing prevalence of the detritus resulting from a progressive demolition of the upper portion of the cone. This, as indicated by a new line of fumaroles, had been fissured early in the morning at a point a little to the east of south, and the fracture had extended downward and formed a vent at about the same altitude (1,200 meters) as that of the subterminal outflow on the northwest side, whose discharge, nevertheless, continued virtually uninfluenced by the lava issuing from a new mouth at the same level. This consisted of a small stream which flowed over the Fiorenza zigzag path used by tourists ascending the mountain from Pompeii, but ceased moving during the day (A, Plate I).

Fig. 24.—First symptoms of the great eruption; morning of April 4, 1906.

So far there was no external indication—except the character of the crater emanations—of any conditions materially different from those that prevailed at the beginning of the northwest flows, but upon the mountain itself, at both the upper and lower stations of the funicular railway, there were observed during the morning very considerable and progressively increasing seismic effects. This fact, with a more copious injection of dark ash into the crater-cloud early in the afternoon and a decided diminution of the northwest flows, indicated a further fracturing of the

cone with consequent injection of lava, which could hardly fail to come to the surface at a lower level. This, in fact, occurred at midnight, and at a point 800 meters above sea-level, 400 meters below and south of, but in the same radius as, the preceding, indicating an extension of the fracture to that point (B, Plate 1).

From this second vent there issued a far more copious and rapid outflow (the first to occur under pressure), which, by lowering the lava-level within the crater, brought about the complete and final cessation of the northwest streams (Fig. 25).

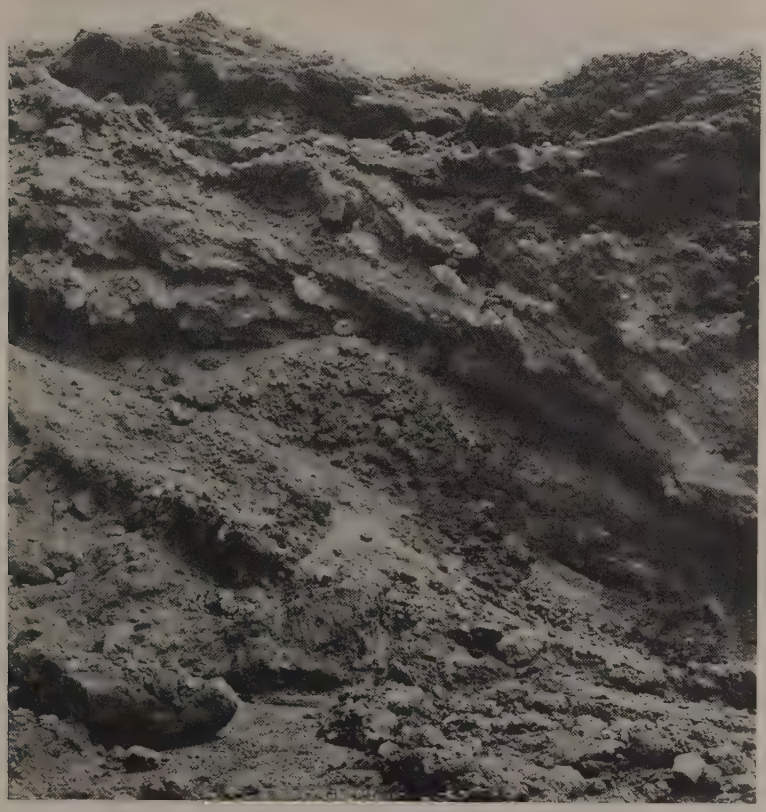

Fig. 25.—Bocca of 1906 as seen in June 1914. Photograph by A. L. Day.

In the meantime the ash-cloud from the crater had, before evening, assumed a threatening aspect, with long, dark streamers floating seaward (Fig. 26), which a veering wind brought over the city by nightfall, and the Neapolitans went about with umbrellas opened against a dry rain of coarse volcanic sand, in a rude awakening to the seriousness of the situation.

On the morning of April 5, by one of the meteorological phenomena peculiar to this section, the crater-cloud was being carried in long, sweeping curves north through west and south over the city (Fig. 27), and the writer, prepared for a long siege, ascended the mountain by what was the last train to run over the Vesuvian railway for many a day.

Above the Observatory, fairly dense, dark volutes of ash-laden vapors shot straight upward from the crater (Fig. 28) with a force which attested explosive reaction to the rapid outflow of the night before—that reaction which forms the basic principle of our hypothesis of the mechanism of the eruption, and which is fully discussed in the "Analytical Section."

Fig. 26.—Ash cloud from crater increasing in volume and veering toward Naples; afternoon of April 4, 1906.

Fig. 27.—Atmospheric currents carrying the crater-cloud over Naples; morning of April 5, 1906.

During the day this emission increased in violence, with the ejection of mixed incandescent lava-masses and old cone-material, blocks of which already fell at a distance of several hundred meters from the crater. Following the stronger explo-

sions (and especially those most densely charged with ash), there began to appear in the midst of the crater-cloud those visible electrical phenomena which later formed so important a feature of the eruption. At this time they consisted of tiny, brilliant lightning-flashes produced by the powerfully projected jets of ash. The flashing took place in all directions, vertical as well as horizontal, these last being upwardly curved like an artificial electric arc; but the others at this stage were short and straight and the sounds were as sharply staccato as pistol shots in the open air.

Fig. 28.—Ash-laden column of vapor shooting straight upward from the crater, April 5; the Observatory tower is at the bottom of the illustration.

Southward the air was clear of ash, and the volcano presented an imposing spectacle (Fig. 29), not unlike that of a gigantic locomotive puffing up a heavy grade and constantly supplied with fresh fuel. Although this activity was of small moment in comparison with what was to come, it showed, nevertheless, the beginning of a higher pressure in the gaseous emission, while the heavy charge of ash gave a clear indication of the progressively serious attack of the magma upon the crater-walls and of the fracturing of the cone itself. The varying qualities of this material during the course of the eruption are studied in the "Analytical Section," but it may be stated here that the product of these first days was coarse in texture and dark in color, consisting mostly of cone-detritus. Ash fell in Naples until noon of this day, when a veering wind carried the crater-cloud elsewhere. It may be emphasized that the fate of any town or section in the vicinity of a volcano during an eruption depends largely upon the direction of the wind and its permanence in that azimuth, the only other determining factor as to direction having been, in this case, the inclined projection of materials to the northeast during the night of the culmination. It was fortunate that the winds of heaven were impartial in the bestowal of their unwelcome gift, for if the 90 centimeters average for some towns and 30 centimeters for others had all been deposited in one direction, that sector would have been buried more completely than was Pompeii, which was spared this time.

The activity of the crater again diminished somewhat during the night of April 5–6, but the lava from the lower opening on the south side of the mountain continued flowing until morning, when, at 8 o'clock, another vent was formed at a still lower altitude (600 meters) (F, Plate 1), which gave forth the most rapid outpour of lava during the entire eruption, except that which was emitted during the night of the culmination.

But this latest opening, although 200 meters below the other, was horizontally displaced to the eastward by five times that amount and could hardly, therefore, be a continuation of the same fissure, unless, indeed, this had extended itself by insinuation between horizontal strata. This may have occurred, as is indicated by the sills seen in section on the walls of the crater. But the subsequent opening of other vents to the east and north makes more probable the hypothesis of a very general and profound fissuring of the great cone in many directions, not all of which fissures, naturally, reached the surface.

Fig. 29.—Vesuvius from the south, April 5, 1906. The white vapors are from lava that issued from near base of cone.

During the day of April 6, activity in the crater again increased to an even greater degree than on the preceding day, forming the third great gaseous reaction to the increasing lava-outflow. An excursion with Professor Matteucci around the base of the cone to the Casa Fiorenza—whose people were warned of the seriousness of the situation and ordered to leave the spot—was continued to the locality of the latest lava-vent, which, as has been said, was at an altitude of but 600 meters above sea-level and was situated on the southeast flank of the mountain, at a spot, above the Lave di Caposecchi, known as the Bosco di Cognoli (F, Plate 1). The mouth was in the form of a low arch, evidently the end of the tunnel into which the fissure had, as usual, been transformed, and from this orifice there gushed forth a mass of intensely incandescent and exceedingly liquid lava, with a velocity of flow which at some 15 meters from the vent was measured as being 5 meters per second.

The main lava vent of Bosco di Cognoli just before and just after the extension of the fracture. The lava is flowing at the rate of 5 meters per second. April 6, 1906.

Although the emission was not explosive, the lava was highly charged with vapor, which issued from all parts of the surface with a strong, hissing sound (Plate 5), the lack of explosive effects being due to the absence of large gas-bubbles. At a moment when we were observing and measuring the velocity of the outflow at the vent, this was suddenly extended upward for some 20 meters or more with a sputtering roar and the ripping and tearing open of solid rock, and a sheet of the glowing liquid shot, for an instant, vertically upward from the long rent to a height of 5 meters and then fell to the new level a redoubled river of fire (Plate 5). This stream was bifurcated and very broad, because of its great fluidity, but its westerly branch flowed as much as 2 kilometers in the first six hours. Following this down the mountain-side in the direction of Boscotrecase, we found that it had destroyed a number of vineyards and a few small houses (Plate 6) and was headed straight towards a part of the town known as "Oratorio." This lava and that of the previous outflows was of the aa type, as is normally the case under these conditions.

Our return to the Observatory was made on foot from Resina, under a shower of rain and a fall of ash from the crater, the activity of which all through the day of April 6 had been greater and more sustained than at any previous time. This ash was of a much finer texture than any hitherto emitted, and the electrical discharges in the crater-cloud were also becoming longer and far more powerful, with an occasional reverberation like ordinary thunder. By midnight all the phenomena had increased in intensity, with sure and repeated demonstration of greater gas-content in, and progressively more active gas-release from, magma which had formerly occupied a lower level in the throat of the volcano and which now rose to take the place of that whose rapid extrusion formed the fiery floods that menaced the towns around the volcano. Nothing could be clearer than this already thrice-repeated revelation of a rhythmic uplift of magma to higher levels, pulsing in surges of ever-increasing amplitude, with consequent liberation of their stored-up energy in the production of these dynamic paroxysms. No earthly power could now prevent the catastrophe, as the explosive reaction to the great Bosco di Cognoli outflow would be terrific. At the Observatory the instruments continued to indicate seismic activity of constantly increasing magnitude.

During the morning of April 7 and until shortly after noon the explosive activity at the crater again gradually diminished—relatively to its latest culmination—but by 2 p. m. this again increased, while still other vents opened at the extremity of the Valle dell'Inferno (Plate 1, G), the lava from which flowed almost due east, in the direction of several small towns, including Terzigno. As on the preceding day, Professor Matteucci and the writer purposed to visit Casa Bianca and the lava streams, but found it necessary to make a wide detour on a much longer radius from the volcanic axis on account of the falling of huge blocks as far outward as nearly to the base of the main cone. Several of these were estimated to weigh as much as two tons, and in falling upon the inclined slope they were generally broken into several fragments, rebounding with great velocity—a danger often experienced in the Alps from rocks dropped upon a slope by an overhanging glacier.

As seen from the south, there were many powerful lightning-flashes in the crater-cloud, which was continually growing in height, and here the writer observed for the first time a phenomenon which he has termed "flashing-arcs."[1] The dynamic activity at the crater took the form of a series of very sharp, sudden, but powerful explosions in rapid succession, there being at times as many as three per second, although the rule was about one every two seconds. The material ejected was of a mixed nature, about equally divided between fresh liquid lava, with incandescence visible in bright daylight, and the dark detritus of the crumbling cone. At the instant of each explosion, but before it could be sensed by the eye or ear, a thin, luminous arc would flash upward and outward from the crater and disappear into space. Then came the projection of gas and detritus above the lip of the crater and in a few seconds the sound of the explosion reached the ear.

Fig. 30.—"Flashing arcs" produced by sharp explosions, of which four are recorded in the photograph; afternoon of April 7, 1906.

The motion of translation of the arcs, while very rapid in comparison with that of the ejected material, was not beyond the limits of easy observation, and the phenomenon is nothing else than the refraction and reflection of light by the condensation-rarefaction spherical shell produced in the air by the explosion, appearing from any given direction as an arc. It is impossible to describe the delicate luminosity, the elegance and perfection of form, and the grace and vivacity of the arcs, amid the contrasting color and relatively sluggish movement of their surroundings, and this phenomenon may be considered one of the most beautiful of all volcanic manifestations (Fig. 30).

Following the lava streams, we found the more westerly one to have flowed another 2 kilometers toward Boscotrecase, but during the afternoon this seemed to have halted near the cemetery. By early evening the eruptive phenomena had reached a condition of extraordinary violence. Another uprising of highly incandescent magma to the upper portions of the conduit was indicated by the truly marvelous brilliancy of the ejected material, which began to clothe the greater part of the cone as with a mantle of fire, while ever higher above the crater rose the great geyser-jets in rapid succession. The writer witnessed this precursory phase of the great culmination from the railway station at Boscotrecase.

[1] F. A. Perret (2).

The main aa flow of 1906, above Boscotrecase. Photograph by A. L. Day, June 1914.

From time to time there were great explosions having a tearing and roaring sound (the true "boati") with sensible air-concussion, and the panic among the inhabitants of these Vesuvian towns can easily be imagined. Toward 10 p. m. masses of cone-material again began to be mixed with the incandescent jets, with consequent renewal of powerful, brilliant electrical discharges in wondrous contrast to the golden spear-heads of the ejected lava piercing the dark detritus-clouds. Then all would again be cleared of ash, and the pillar of liquid fire—maintained continuously at a height of several kilometers by multiple projections from all parts of the magma column within the conduit—illumined the Gulf of Naples from Capri to Miseno. At 10^h20^m p. m. and at 10^h40^m p. m. two brilliant fountains of fire upon the flank of the mountain seemed at first to indicate the opening of new craters at these points, but they proved to be a violent renewal of activity at the lava-vents of Bosco di Cognoli and the Valle dell'Inferno. From these there issued veritable torrents of lava (Plate 6), which in a few hours reached the first houses of Boscotrecase and later crossed the town (Plate 7) and the Circum-Vesuvian railway. A branch stream threatened the city of Torre Annunziata, but fortunately stopped the next day just before reaching the cemetery. The lava from the Valle dell' Inferno vents also ceased its flow just before reaching Terzigno.

In all probability it was at this time, or possibly a little earlier, that lava broke through the wall of the cone on the north-northeast side. This occurrence was not observed and its date is therefore uncertain. The outflow was quantitatively of small moment, but it was of notable importance as being the principal cause of the formation of a considerable depression—the "échancrure" of Lacroix—on the rim of the crater, to whose agency has been ascribed the oblique ejection of material in the direction of Ottajano (p. 43). This final but almost momentary rising of the magma to so high a level within the conduit was also indicated by what seemed from Boscotrecase to be a reemission of lava from the earlier Casa Fiorenza vents high up on the mountain-side. This simultaneous drainage from so many points, together with the enormous upward projection, effected the definite removal of that material which had pressed most powerfully down upon the principal accumulations of the active period in and under the volcano, and whose expansion would now cope with the inevitable downfall of the upper portion of the mountain, no longer supported by the column of heavy liquid which had occupied its interior.

As the writer reascended the mountain toward midnight, all the phenomena increased in violence, the seismic effects being especially noticeable even before the Observatory was reached. At 12^h37^m a. m., April 8, a strong shock was felt, followed soon after by visibly greater explosive activity at the crater. At the altitude of the Observatory the ground was in constant motion. There was, in a word, a continuous earthquake, and for some hours (which constituted the period of dynamic culmination) it was impossible to stand quite still. Within the building it was difficult to cross a room without steadying oneself with a hand against the wall. To make sure of this not being merely an oscillation of the structure, the writer went outside and braced himself against a stone wall; but the effect was the same—like the shell of a humming boiler the mountain was pulsing and vibrating contin-

uously, but with a period and an amplitude proportionate to its size. As nearly as could be determined, the period was about half a second.

Of the crude instruments in the Observatory, described in another place (p. 136), the 42-centimeter simple pendulum corresponded most nearly, in its period of oscillation, to that of the earth motion, swinging as much as 25 centimeters and often striking the wall. Needless to say, the more sensitive instruments, such as the Agamennone double pendulum, were thrown completely out of gear. That the Observatory did not fall can be accounted for by its good construction, the shortness of the seismic period, and the roughly pyramidal form of its design. The walls were later found to be cracked, nevertheless, in an east-west direction, and there can be little doubt that a small increase in the maximum earth-movement during that night would have at least thrown down the tower.

The obvious peril to the Observatory drove us out-of-doors, where at only 2.5 kilometers from the radiant column of incandescent pasty fragments—at this time already 300 meters in diameter and 3,000 meters in height—the air was so cold as to constrain us to build a fire and sit close about it for warmth. This condition was caused by the aspiration of cold air from the sea by the tremendous updraft of the pillar of fire, causing upon the mountain-side a cold wind of considerable velocity.[1]

The most alarming feature at this time was the continuous increase—each earth-shock felt above the regular pulsation was stronger than its predecessor; each wave-crest on the sea of sound was louder than the one before; the jets of the great fiery geyser shot ever higher into the dark, overhanging pall of blackness that extended over our heads and fell westward in a thick veil, through which, from Naples, could be seen only fitful gleams. But between the Observatory and the crater all was clear, and it becomes increasingly difficult to describe the events of the great culmination in words befitting a scientific book.

The accumulation of incandescent material upon the cone resulted in constantly lengthening slides of the fiery masses, which, if it were not for the brief duration of their manifestation, would merit classification among the great phenomena of the eruption, with perhaps the title of "fire avalanche." In consequence of these, the lower funicular station was seen at 3 a. m. to be burning, and we could not but admire the intense contrast of its clear yellow flames with the indescribable lurid glare over the rest of the visible universe.

At 2^h30^m a. m., April 8, there came a second powerful earth-shock, which nearly threw us to the ground. The wooden chalet near the Eremo restaurant (Plate 4), in the partial shelter of which we had built our fire, was wrenched around with a peculiar, squeaking sound of all its timbers. Like the former shock, at 12^h37^m a. m., this was a simple forward-backward-forward throw, which constitutes, it would seem, a seismic manifestation peculiar to the culminating period of great eruptions (p. 83). This strong shock was at once followed by great downfalls at the mountain-top, and from this moment a condition was reached where action,

[1] The low temperature was caused chiefly by the adiabatic expansion of the air on rising from the sea-level to that of the Observatory: see Humphrey, W. J., Physics of the air, pp. 31, 34, 1920. (H. S. W.)

Lava-flow of 1906 in Boscotrecase. Photograph by A. L Day, June 1914.

reaction, and interaction combined to effect a release of energy that nothing but exhaustion could bring to an end.

With increasing amounts of detritus, the electrical manifestations now reached an appalling intensity, not only in frequent long discharges from the crater-cloud to earth, but also through conduction, by the overhead equipment of the Vesuvian railway, to our location. Arcs were burning at the lightning-arresters in the Eremo station, and some flashes passed directly from the aerial wires to earth. The station-master said later that he had seen these wires red-hot, but this was not observed by the writer.

Meanwhile, a gradual change had been taking place in the conformation of the great column of gas, lava, and detritus rising from the crater, part of which, losing its vertical direction, shot more and more obliquely to the northeast till it formed a giant arch overspanning the crest of Monte Somma in the direction of Ottajano, while the rest of the column continued straight upward. This inclined jet was the cause of great disaster to the cities of the plain lying in that direction, Somma Vesuviana, Ottajano, San Giuseppe, etc., where the accumulation of fresh scoriæ, old rock-masses up to 3 kilograms in weight, lapilli, and ash caused the crushing in of many roofs, including that of a church in San Giuseppe. This phenomenon was a repetition of what often had occurred in great eruptions of this volcano, especially in 1649, 1737, 1779, and 1847, and its cause will be discussed in the "Analytical Section" (p. 63). Ottajano was partly buried under nearly a meter's depth of this material, the greater part of which—in spite of its luminosity during the upper portion of the trajectory, as seen from the Observatory—seems to have fallen in a sufficiently cooled condition to cause the ignition of but few substances. The electrical discharges between this jet and the earth were frequent and powerful and caused considerable damage, with possibly the production of globe-lightning,[1] a phenomenon not observed during this eruption in the crater-cloud itself.

The rain of projectiles at Ottajano resulted, naturally, in the breaking of most of the window-glass, in many cases with the formation of more or less perfectly circular openings. This and the fact that the majority of the perforated windows were on the side of the buildings facing not toward, but away from, the volcano has given rise to much discussion (p. 65).

At 3^h30^m a. m., April 8, there began the true dynamic culmination of the great eruption, with a literal *unfolding* outwardly of the upper portions of the cone in all directions, like the falling of the petals of a flower. Those who speak of the top of the mountain having fallen *in* were not eye-witnesses of what occurred. No mass of matter, however great, could descend against the mighty uprush of gas that was now liberated from the depths; at most, it could slide down the oblique walls of the cup-shaped cavity, only to be caught by that great blast and tossed upward and outward, like a light ball upon a fountain-jet. This colossal column, with ever-increasing acceleration, was actually coring out and constantly widening the bore of

[1] G. Mercalli (3).

the volcanic chimney; yet, in spite of the power of its emission, the emanations gradually became less luminous, although the coming of daylight unfortunately detracted from the exactness of observations on this important point. The trepanning action of the great blast tore from the walls of the conduit the material of the many dikes there exposed, and fragments of this compact gray rock now began to fall from the skies till it became necessary always to stand erect and with a rolled-up overcoat held as a cushion upon one's head. At first of the size of small nuts, the projectiles gradually increased up to 2 and 3 kilograms in weight, some of which were thrown as far as the power station of the Vesuvian railway, 4 kilometers from the crater. On account of this rain of stones in the open and the threatened falling of the Observatory tower, together with the ever-increasing opening of the main cone, Professor Matteucci and the head of the little band of carbineers ordered us farther down the mountain-side, where only the smaller stones were falling; from here we witnessed that majestic intermediate phase of the eruption left unspecified by others, but whose importance it becomes the writer's task to demonstrate in the next chapter.

INTERMEDIATE, GAS PHASE

The non-recognition, by other writers, of this transition period as a distinct phase of the great eruption is probably due to their not having been privileged to observe its phenomena from a vantage-point which revealed the true characteristics. Thus, Mercalli[1] writes:

"From Naples the entire mountain appeared enveloped in a great cloud of reddish dust, but above this arose, at brief intervals, immense cauliflower clouds."

Brunhuber[2] (also observing from Naples) says:

"Vesuvius was entirely hidden by a dark cloud; . . . . . the din was very great—a deep, rising and falling but quasi-continuous, rumbling constantly increasing and culminating at 3^h30^m in a terrific roaring. During this time the open doors in the hotel were oscillating uninterruptedly like horizontal pendulums."

But on the mountain the visibility was perfect, and however incompetent the present writer may feel to present a word-picture of this great culmination, some narration of its features must be given.

Briefly stated, the fundamental, outstanding characteristic of this manifestation was the paroxysmal emission of gas. Just as in the preceding luminous phase the predominant feature was the ejection—fluent and explosive—of incandescent, liquid lava, and as in the final dark phase the preponderating ejected material consisted of ash, so that which most strongly characterized this intermediate period was volatile matter—a liberation of intensely compressed vapor and gas. It is true that ash was ejected in quantity and to an enormous height, and was borne far and wide in the direction of the prevailing winds, but in comparison with the stupendous volume of the escaping vapor the solid matter was quantitatively almost negligible.

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[1] G. Mercalli (3), p. 14.

[2] A. Brunhuber, *Beobachtungen über die Vesuveruption in April, 1906: Beilage zu den Berichten des naturwissenschaftlichen Vereins Regensburg*, Heft X.

By daylight of April 8, the seismic movements had diminished in intensity, all the liquid lava had been ejected, and the throat of the volcano was clear, but from a source, the depth of which is wholly unknown, there rushed forth through the central tube a continuous blast of gas, reaching heights as great as 13,000 meters (Fig. 31).

Fig. 31.—Drawing (scale, about 1: 100,000) showing conditions during the explosive culmination at 3 p.m. on April 8. The section is from north to south and extends down to sea-level.

The writer (at 3 kilometers from the base of the column) looked vertically upward to observe that, at the very top of the lofty pillar of cloud, great globular masses of vapor were expanding outwardly against the surrounding air-cushion with incredible velocity, forming "cauliflower heads" with a sharpness of contour and a wealth of detail impossible to describe. That which staggered the imagination was the revelation of stupendous initial pressure. Let the reader think of globular masses of compressed vapor almost exploding in the air at more than 10 kilometers above the vent, and then try to imagine the original tension of the gas and the degree

of its acceleration within the shaft of the volcano. An interesting feature was that the excessively rapid upward and outward projection of the vapors against the cushion of air filtered out, so to speak, their content of ash. At such extreme velocities this solid, though finely divided, material was screened, as it were, from penetrating as far as the gas could go, so that the upper and outer edges of the great cauliflower masses were of the purest white and closely resembled condensed steam.

The maximum gaseous development occurred at 3 p. m. of April 8 (diagram 2, *h*, p. 141). The problem of the mechanism of this phase must be reserved for the "Analytical Section," in order to conserve the narrative form in this part of the work; but one point should here be impressed upon the reader who desires a true conception of this manifestation, and that is the idea of *continuity*. The use of the word "explosion" is unfortunate in conveying the thought of a sudden outburst followed by calm, and "emission" is preferable, providing it can be made to carry the idea of unlimited power. During the phase we are now considering, the gaseous outrush was no less constant than the "blowing-off" of a steam-boiler after the water has been ejected or (to take an example even more familiar) the emission of steam from a safety-valve.

The sound, also, throughout the entire culmination, was an uninterrupted, compound note not unlike the roar of Niagara, but with a recurrent crescendo-diminuendo effect giving to this phenomenon, along with all other manifestations of the great eruption, the wave form. Above the curve of dynamic intensity—itself a slow wave synchronizing with the still slower one of luni-solar influence—there were superposed these rolling cadences of sound, the seismic pulsing of the ground, and the exceedingly rapid undulations of the electric flashes in the cloud. The great eruption was a sublime manifestation of rhythm.

Strongest of all impressions received in the course of these remarkable events, greatest of all surprises, and most gratifying of all features to record was, for the writer, that of an infinite dignity in every manifestation of this stupendous releasing of energy. No words can describe the majesty of its unfolding, the utter absence of anything resembling effort, and the all-sufficient power to perform the allotted task and to do it majestically. Each rapid impulse was the crest of something deep and powerful and uniform which bore it, and the unhurried modulation of its rhythmic beats sets this eruption in the rank of things which are mighty, grave, and great.

There was present also the element of awe, in all its fulness. The phenomena entered, through their intensity, that sphere where the normal conditions of Nature are overpassed, and one stands in the presence of greater and more elemental forces than any he has known hitherto. This tends to induce a state of mind which hardly recognizes as entirely natural this transformation of the visible universe, and with difficulty one accepts the dictum of reason, that all will pass and the normal return as before; and so, for the many, the events of this and the succeeding days of ashy darkness seemed to show that—even as the younger Pliny wrote of similar conditions in this same region nearly two thousand years ago—"the last eternal night of story has settled on the world."

But it is precisely this projection beyond the borderland of the obvious which gives to such events their majesty—the dignity which, allied with the mysterious, is thereby perfected. The sense-walls of the universe are shattered by these higher values of power, and Deity is indirectly more in evidence than in the case of lesser things. A blade of grass as surely, but far less forcibly, reveals the truth that That which manifests can not be seen, nor heard, nor felt, except through and because of the manifestation.

Fig. 32.—View of Vesuvius from Naples, morning of April 9; beginning of the dark, low-pressure, ash phase.

A tentative excursion to the Observatory was made in the afternoon of April 8, but, finding that the stones continued falling, it was decided to postpone our definite return until morning. The writer took advantage of this to make his way to Naples and send a cable to America. At midnight, exceedingly powerful electric discharges were heard, with long reverberation, indicating renewed injection of detritus into the crater-cloud, and, inasmuch as this could hardly have occurred under the sway of the ultra-powerful blast of gas, there was reason for supposing the end of the "intermediate phase." This may be said, thus, to have prevailed during the daylight hours of April 8 (Palm Sunday) and to have formed—remaining always specific and distinct—a nexus between the (first) luminous liquid-lava period and the (third), dark ash-emitting phase, whose phenomena will now be narrated.

DARK, ASH PHASE.

At Naples, on this day of April 8, conditions were indescribable. The earth-shocks of the night before had produced a state of panic, and it is said that 100,000 persons left Naples in five days. At each return of the crater-cloud, with its

darkness and its showers of ash, processions filled the streets, invoking the intercession of the saints.

Very powerful electrical discharges during the night prepared the writer for a great change in the nature of the eruptive processes, and the morning of April 9 revealed the emission of a truly imposing volume of ash, apparently from a greatly widened crater, but under a gas-pressure so reduced as to constitute a radical change from the conditions of the previous day (Fig. 32). There had thus supervened this (third) last and longest phase of the eruption, and it behooved the writer to return to his post. This was attended with some difficulty. A cab was engaged and proceeded in the direction of the volcano, but against a tide of humanity fleeing—afoot, in carts, on donkey-back—from their endangered homes. The behavior of these stricken folk was admirable, and a greater patience, resignation, and "savoir faire" could hardly have been expected of any race. An interesting feature noted by the writer was that the children had, so to speak, taken charge; it was they, rather than their elders, who were directing the flight, suggesting destinations, urging on the beasts.

Before Resina was reached, the downward blasts of ash and sand became so heavy that the horse could go no farther, and the rest of the trip was made on foot. Here were enacted scenes like those which Pompeii must have witnessed, and through the ash-engendered darkness faces peered from doorways, from under wagons, and from every place of shelter from the volcanic storm. Still farther on, and more especially upon the mountain itself, the down-sweeping ash became conglomerated through condensation of the water-vapor in the crater-cloud, forming balls of soft mud, some as large as an egg. During the two following days the production, by this means, of "pisolites" was on a gigantic scale, although they were of small size compared with others found by the writer at Kilauea and among the ancient ejected material of Vesuvius (Fig. 33).[1] It would be difficult to imagine a more thoroughly aqueous phase of gaseous emission than that of April 8, 9, and 10, and the significance of this feature in connection with the mechanism of the eruption is considered in another place.

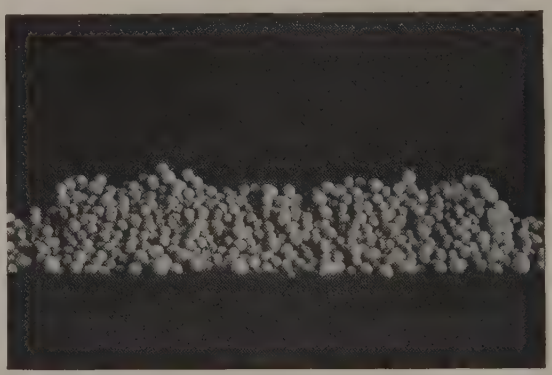

Fig. 33.—Pisolites (natural size) which fell from water-charged crater-cloud, April 9 and 10.

At Pugliano the writer met Mormile, the station-master, who volunteered for service as telegrapher, and the remainder of the ascent was made via the ash-buried bed of the Vesuvian railway. Matteucci awaited with open arms, not having believed that the writer would return.

[1] Similar pisolites are abundant in the ash scattered over the Kau Desert by the great explosive eruption of Kilauea in 1789. See T. A. Jaggar, Bull. Hawaiian Volc. Observ., *8*, 114, 1920. Specimens of these collected by H. S. W. in 1920 vary from 2 to 5 mm. in diameter. Pisolites were found also by Lacroix in some of the ash-beds of Mont Pelée (La montagne Pelée, Paris, 1904, p. 419) and by Pratt at Taal, Luzon, (Jour. Geol., *24*, 450, 1916). (H. S. W.)

Ash was falling heavily but dry, and with it fell countless living caterpillars.[1] The seismic instruments were relatively calm and, after repairs had been effected, were of the greatest value in the study of dynamic processes during the long intervals of darkness.

There was thus begun a period of trying, tedious, comparatively unexciting living, with intense discomfort and suffering at times, to which the writer will not again refer. Our little group consisted of Matteucci, Brigadier Migliardi, with the six carbineers under him, Mormile, and the writer (Fig. 34), and it is to a brief account of the daily observations and excursions made during this time that the remainder of the "Narrative" is devoted.

Fig. 34.—The mountain under its mantle of white ash; seen from a terrace of the Observatory; in the foreground Professor Matteucci and carbineers.

The fact that we remained at the Observatory had an effect on the general population which may be mentioned here, although it is foreign to the narration of our experiences. Daily telegrams (sent by courier when the wire was down) were printed in poster form and prominently displayed at Naples and all Vesuvian towns, and the quieting effect of reliable and steadying reports from the front may well be imagined. If men could live upon the mountain itself, life was surely possible elsewhere. Aside, therefore, from direct aid (p. 54), this practical result of volcanic research will be seen to have been, from a humanitarian standpoint, not entirely negligible.

During this day of April 9 we observed the first of the "hot avalanches" (Plate 8 and Fig. 35). The accumulation of ejected material upon the upper portions of the cone attained a depth which at times and in places was not less than 15 meters. This material consisted partly of blocks and cone detritus, but principally of deep, superposed strata of fine ash, intensely hot. This material was not only poised in exceedingly unstable equilibrium, but was in a peculiar state of potential mobility, due to the high temperature and consequently *dilated* condition of the interstitial gas. Under these circumstances there was needed only a strong tremor from below or the fall of a heavy boulder from above to detach tons of this material, which (in virtue of the peculiar conditions described above) descended the flank of the mountain with the velocity and aspect of a snow avalanche in the Alps, but

[1] For the occurrence of insects during the Vesuvian eruption of 1872, see Palmieri, *The eruption of Vesuvius in 1872*, London 1873, p. 97. (H. S. W.)

generally in a silence as impressive as the sound of the other is terrifying. These hot-ash flows continued at intervals for many days, and their contribution to important morphological alterations through transportation of material, with the formation of breccias and the furrowing of the cone with channels as guides for subsequent erosion (p. 91), was a distinct feature of the great eruption and will be specifically considered later in the course of this work (p. 89).

On the morning of April 10 the Observatory seismoscopes were quite strongly agitated and the crater-cloud once more was sent upward with some force during the morning hours, but later it arched over toward the southwest and finally actually came to earth and swept down the mountain-side over Torre del Greco (Fig. 36). By this time virtually all electrical discharges within the crater-cloud had ceased, but the cloud itself was strongly electrified as a whole and in opposition to the earth,

Fig. 35.—The hot avalanche of Plate 8 passing in front of and below the Observatory.

to which it was powerfully attracted. This explained—at least in part—its peculiar manner of descent, as the prevailing wind had only sufficient power to determine the direction of its fall. In making, during the afternoon, our first excursion upon the mountain-side after the great culmination, it was necessary to pass under and through this cloud of gas and ash, and before coming to within 500 meters of its nearest edge the electrical potential was so powerful that a "brush discharge" (St. Elmo's fire) was developed on every pointed object upon our persons, this being first noticed by a hissing sound from the metal stars upon the caps of the carbineers. A stick held aloft, or even a finger, was sufficient to produce an "electrical wind," strongly audible, and long, loose hair would certainly have "stood on end." As we passed through the cloud the electrical attraction was still further demonstrated by the violent impact of the coarser grains of sand, which scratched the skin and cut the lips to the point of bleeding, and there were moments when we were not cheered by Matteucci's remarking, "This is how Pliny died." But the gases, although hot and seemingly rather wanting in oxygen, were by no means irrespirable, and the

lack of those powerful acid vapors (HCl, SO_2, SO_3, H_2S) whose emission characterizes the lesser phenomena of volcanism was surprising.

It was found necessary to make a wide détour in order to keep clear of the exceedingly rapid hot avalanches which occasionally swept downward, and even the

Fig. 36.—Strongly electrified crater-cloud descending southwest flank of Vesuvius.

Fig. 37.—An ash-cloud rising from the enlarged crater and attracted to earth by a strong electric charge. The collapsed area on the southeast flank is also shown.

material deposited from them—filling all hollows with an intensely hot, dry quicksand, through which a small stone sank readily and in which an unwary foot would be burned—formed a serious obstacle to these excursions (p. 91).

Arrived at length below the site of Casa Fiorenza, this was found to have disappeared and the entire locality to have been transformed beyond recognition by a

great, roughly oval collapse upon the southeast flank of the cone, which undoubtedly had resulted from internal drainage of lava by the rapid outflows on this side of the mountain. The collapsed area had already been eroded by avalanches, as is seen in Fig. 37, which also shows the serpentine conformations assumed by the ejected ash-clouds under the conflicting influences of ascensional heated gas and electrical attraction acting with gravity.

On this day, and especially during those intervals when the emission of gas was temporarily more powerful, the ash-cloud attained probably its greatest density, of which some idea may be had from the frontispiece. Bearing in mind that the smallest diameter of the rising column of ash-laden gas was from 600 to 700 meters, the reader will be able to form some idea of the truly enormous volume of material.

As we proceeded down the slope, we found no movement in the various streams of lava, although it would seem that during this same night there was another ephemeral outflow from one of these vents. Mercalli found slow movement in the small eastern flow toward Terzigno on April 9.

April 11 was for us at the Observatory in great part a day of darkness. The ash fell heavily, this time bringing many flies, and there began for us a long series of periods of obscurity, some lasting for 8 hours or more, in which there was absolutely no difference between night and day and the darkness was literally of the kind which could be felt. During these times there was little to do but wait until a change of wind sent the crater-cloud in another direction to shed its ash anew upon some unfortunate town whose inhabitants were beginning to believe that the great scourge was at an end.

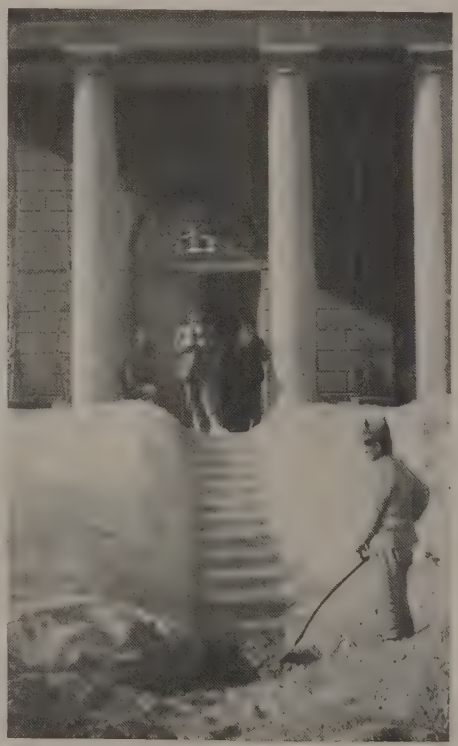

Fig. 38.—Deposit of ash at portico of Observatory.

At 7^h40^m a. m. of April 12 a strong seismic shock was felt, and again throughout the day the Observatory had visitations of heavy showers of ash. A force of sappers was brought up from Resina, and from one roof-terrace alone six tons of this material were cleared. Fig. 38 shows the accumulation upon the steps of the portico.

On April 13 another shock was felt at 7^h30^m a. m. The crater-cloud veered southward and again our side of the mountain was clear, permitting the satisfactory photographing of one of the larger hot avalanches, which, starting down the cone directly toward the Observatory, was deflected by the intervening lava cupola (Colle Umberto I), which it almost surmounted (Plate 8), and passed below and in front of the Observatory (Fig. 35), having covered a course of about three kilometers in a few seconds.

Hot avalanche descending the cone directly toward Observatory, but deflected by the lava cupola of 1895, April 9.

Outside our little universe, dominated always by the crater-cloud of ash and gas curving overhead in an apparent descent to the horizon, the weather was evidently clear, and to the southward, beneath this arch of blackness, serenely shone the evening star.

The morning of April 14 saw the crater-cloud somewhat increased in size, and at 9 a. m. a small seismic storm kept the instruments in constant agitation, while during the afternoon a number of strong electrical discharges were heard, evidently passing between the cloud and the earth on the opposite side of the mountain. Toward evening there ensued a period of relative calm, with the ash-cloud arching eastward at no great height and offering wondrous chiaroscuro effects in the light of the setting sun (Plate 9). During the night, however, there were several earth-shocks, with a strong renewal of hot avalanches on the day of April 15, and once more the eternally recurring rain of ash.

Fig. 39.—Vesuvian landscape of April 1906.

The seismic agitation soon subsided, and during this gray day there prevailed a presentation of *negativity* that is impossible to describe. As far as the eye could reach, there was not one note of color; all was of one uniform neutral tint. There were immense spaces of absolute silence, broken only by the distant tolling of a bell or the siren wail of some steamer seeking its way across the dust-enshrouded bay. The only visible outlines were the nearly formless details of ash-bedecked lava-flows in the immediate vicinity, and the Vesuvian landscape showed in almost imperceptible relief against the gray boundaries of our little world (Fig. 39).

On the following day, from 9^h30^m a. m., for another eternity of a few hours duration, the obscurity was again literally absolute, but with the seismoscopes at rest. By 4 p. m. the veil had lifted and revealed the ash-cloud soaring upward in

huge spiral volutes, a condition due undoubtedly to temporarily inclined positions of the ejecting vents, probably caused by collapsed material (Plate 9).

At 1 a. m. of April 17 an earth-shock was registered, but the remainder of the day was seismically calm. A rapid fall of the barometer presaged some important meteorological event, and the prediction was indeed verified on the following day, when, at 4^h15^m p. m., a voluminous hot avalanche was observed.[1]

By this time the gaseous emission included a considerable percentage of carbon dioxide, as was made known to us at noon of April 18, when an easterly gale began to deflect the crater-cloud directly over the Observatory. For some time before the main ash-laden body of the cloud was borne down upon us there was noted a curious sensation of heat about the feet and legs and an indescribable feeling of oppression, with slight difficulty in breathing—the symptoms characteristic of this heavy but invisible gas, evidently pouring down the mountain-slopes in advance of its carrier. By 2 p. m. the gale had increased, the ash-cloud was driven violently to earth, and it became a matter of life and death to gather into the shelter of the Observatory the members of several families who, the day before, had ventured to return to their homes upon this part of the mountain in the conviction that the worst of the great eruption was past. These people—some forty in all, together with the soldiers and carbineers, and including one woman and several children—were gotten in safety as far as the barracks near the Observatory, but the place offered no shelter for such a number and the difficulties in the way of reaching the Observatory were extreme. It should be remembered that seeing was impossible; even a compass held in the hand was invisible. The road was buried under ash, and all sense of direction was lost in the whirling gusts of wind filled with cutting sand which could not be faced, while the large content of carbon dioxide rendered the air almost irrespirable. All were attached to one long rope, and this human serpent moved like a giant worm from one known spot to another until the goal was reached. Within the building, although the air was filled with the finer ash and the deleterious gas could not be wholly excluded, the conditions were such that existence seemed possible; but one old man nearly succumbed, and a youth of 19, with a recent history of bronchitis and whose coughing during all this time was continuous, died not long after. At midnight the gale ceased and the gas-cloud again arose above the crater, as was shown by the almost instantaneous and quite indescribable feeling of relief experienced by all. Rain fell toward morning, and it was found that the telegraph-line again was broken as a result of the blast, and the daily telegraphic report once more was sent by courier. This day of April 19 was seismically quiet.

April 20 was uneventful, the ash being projected to a lesser elevation, although still copious and with a noticeable increase in the emission toward noon. The weather was fine, the wind west, and the seismographs were quiet.

Virtually the same conditions prevailed on April 21, until 4 p. m., when the seismoscopes were agitated, the crater-cloud increased in density, and some ash again fell in our direction.

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[1] Was not the lowered barometric pressure the cause of the ensuing emission of carbon dioxide? (H. S. W.)

Various aspects of the declining crater-cloud, as seen from Observatory. April 14-16

On April 22 all the seismic instruments were in a state of perfect quiet, and during the day we of the Observatory were honored by a visit from the Duke and Duchess of Aosta, who, like the King and Queen, had been indefatigable in cheering by their presence and relieving by their charity the stricken populations of the Vesuvian towns during the preceding days. The eruption, dynamically, was virtually at an end, as the seismoscopes often stood motionless for hours at a time,

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Fig. 40.—Last phase of the emission of ash.
Fig. 41.—Remains of lower funicular station; note stratification of ash deposit in upper right-hand corner.

and the crater-cloud of ash and gas—though still rising majestically and in successive puffs due to soft explosions—had an ascensional power barely sufficient to raise its heavy content of ash, which could be seen falling in vertical streams in the midst of the ascending vapors, while some of the puffs had only sufficient force to overturn their charge of ash upon the outer lip of the crater, where it often began to slide down (Fig. 40).

During this period and throughout the following days there were many distinguished visitors—scientific, royal, and the merely curious—including Professor

and Madame Lacroix, Johnston-Lavis, Löczy, Jaggar, Brun, Tempest Anderson, ex-Empress Eugénie, King Edward VII, with Queen Alexandra and Princess Victoria, Sir Thomas Lipton, and many others.

On April 23 the seismoscopes were motionless, and on the 24th we made a visit to the crater in a strong southwest wind and with underfoot conditions that reminded one of Palmieri's dry remark, after the eruption of 1872, that "the ascent took more time, and the descent much less time, than before" (Fig. 41).

The extraordinary dimensions of the crater left by this eruption were immediately apparent, but no measurements could be made because of the thick masses of vapor which still filled the great gulf (Figs. 42 and 43). The aneroid gave 1,220 meters as the highest point of the rim, situated in the southwest sector, from which point the crater-lip sloped downward to what was evidently a very considerable depression toward the north and east. This would indicate a reduction in height of the mountain by the amount of 115 meters as a minimum, while on the northern and eastern sides the loss of height would be much greater. It may be interesting to note here that Siniscalco[1] gives the reduction in height of the Vesuvian cone, as a result of the great eruption of 1872, to be only 15 meters.

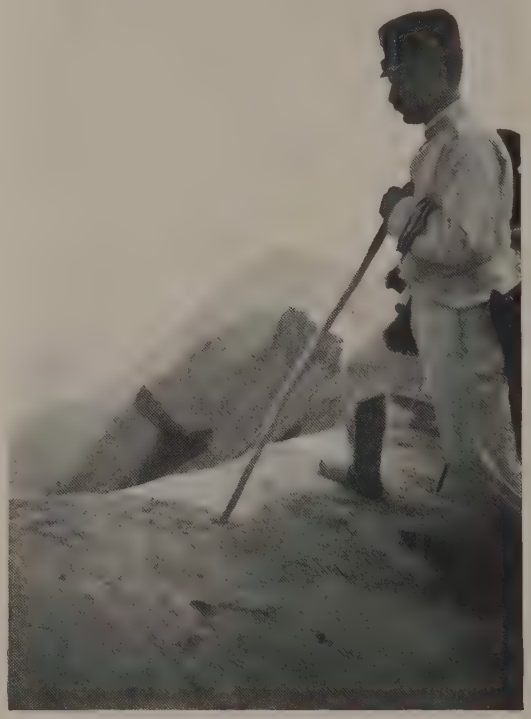

Fig. 42.—Detail of crater edge at end of eruption.

April 25, instruments motionless, except temporary agitation at noon and more strongly at 3^h25^m p. m. Strong west wind.

April 26, seismoscopes perfectly quiet. Wind west.

April 27, seismoscopes motionless, but slow earth-waves caused a swinging of the longer simple pendulum (p. 136). Very heavy rain.

On April 28, at 6^h40^m a. m., there was an explosion with strong agitation of the instruments, and as a result of the abundant rainfall one of the great "mud lavas" was formed, which flows, by invading the Vesuvian towns, were the cause of much damage and even loss of life—a post-eruption phenomenon elsewhere fully described (p. 102).

April 29, instruments quiet. The writer made his first ascent of Monte Somma, after the eruption, from the crest of which the changes in the cone and crater

[1] C. Siniscalco, *Istoria del Vesuvio e del Monte di Somma.* Naples, 1890.

could be observed to greatest advantage. The dip of the top of the cone in that general direction left the crater partly open to view, and comparative views made on this and during succeeding excursions show better than any verbal description the general form and characteristic details of the mountain in its post-eruption condition (Plate 10). After the decapitation of the cone and the formation of its great crater, the most salient feature was the fluting of the external slopes of

Fig. 43.—Crater edge, showing normal angle of repose.

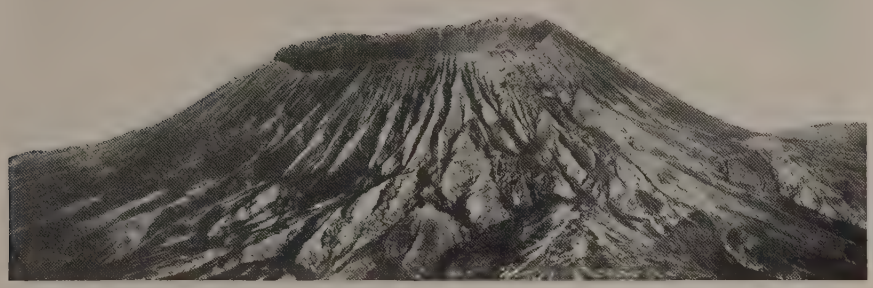

Fig. 44.—Vesuvian cone after the eruption, as seen from Cognoli di Ottajano (Monte Somma).

the cone in deep grooves scored in nearly all directions by the hot avalanches (Fig. 44). But full description of the conditions relating to morphology must be relegated to Part III. Wind-formed spiracles of the exceedingly fine superficial ash were numerous at this time. Their rotation was rapid, with very slow movement of translation.

On April 30 all was quiet, and on May 1 the writer returned to Naples for a short period.

ANALYTICAL STUDY.

MECHANISM OF THE ERUPTION.

In this section, and in the succeeding studies of the various phenomena which characterized the great eruption, the author proposes to reduce all arguments to their simplest expression, in an endeavor to avoid, so far as may be feasible, the complication of hypothetical and theoretical arguments and in order to concentrate upon a few fundamental principles which seem to be indicated by the studies which it has been his privilege to make in actual observation of the revealed phenomena.

The character of a volcanic eruption is generally designated as "explosive," "effusive," or "mixed," the "explosive" character being usually assumed to be associated with outbreaks from trachytic and andesitic magmas, and the "effusive" with the more basic and readily fusible types. But this distinction can be maintained only with great reserve, inasmuch as many of the more acid volcanic cones are built up of lava outpourings as well as of fragmental deposits, while in the basaltic Vesuvius, and other volcanoes of similar nature, the most violent explosive phenomena often accompany the molten flows. In a word, each type of magma may show both classes of phenomena, and there are clearly indicated conditions which—more than the mere difference of fusibility—control the nature of the manifestation and determine the mode of action during the various phases of an eruption. For example, whether the conduit has been normally open or closed during the period of accumulation antecedent to the eruption proper is an important factor.

But before proceeding to consider in detail the effects of this specific condition, we shall venture to postulate some even more fundamental assumptions regarding the mechanism of eruption which observation would seem to have proved to be true:

1. The filling of the crater with magma from the depths is a slow process.
2. There results an accumulation of liquid material within and beneath the volcanic edifice, with gradually increasing gas-content and tension.
3. The release and discharge of all or part of this accumulation constitute eruption and with consequent exhaustion give to the cycle of manifestation its quality of periodicity.
4. The eruptive element, par excellence, is gas.
5. The main function of the magmatic reservoir is the evolution and accumulation of gas.
6. The actual upward movement of magma from its reservoir is too slow to permit of its being the carrier of all the gas which is emitted, whence we may deduce: The magma is a paste which permits the transfusion of gas and which changes into liquid lava in the upper part of the column.

To these should be added one which may provoke criticism, namely, that the original magma during its ascent through and sojourn in what we may call surface conditions will be exposed to water and air, and that the assimilation of these modifying elements constitutes the mainspring of the physical and chemical

Views of Vesuvian cone from a point on the crest of Monte Somma, showing changes in outline produced by internal avalanches.

activities and of the prolonged existence and repeated functioning of the volcanic vent itself.

That the magma, under usual conditions, rises from below with extreme slowness seems to be demonstrated by the ending of a great eruption through exhaustion of the accumulated materials and by the observed very gradual ascent of lava in the open conduit during the succeeding period of activity.

The increase of gas-content in the magmatic column—considered in point of time and even more especially of space—will proceed in a widely different manner according as the volcanic chimney is normally open or closed.

We may first consider, very briefly, the case of a closed conduit, in order to accentuate, by contrast, the conditions that prevailed during the eruption, which is the special object of our study. The closed condition preceded the famous Vesuvian outbursts of 79 and 1631, and, as it is also normal for most volcanoes with acid lavas, the type of eruption resulting therefrom has become classic and the one whose mechanism is most generally recognized.

The principal result of accumulation under closure is extreme gas-saturation of the uppermost magma, together with a series of occult operations differing according to variable local conditions, among which the solution of the containing-walls may play an important part. The immediate effect of release will be the prompt, and more or less forcible, ejection of the upper portion of the magma in a state of subdivision that will depend upon the nature of the material and its physical condition at the moment of emission, and especially its gas-content. It is obvious that such material can not *flow* in a coherent stream; instead, it will be shot upward by the powerful gaseous expansion in the form of finely divided, more or less vitreous ejecta. In general, the ejectamenta will be of increasing compactness as the lower material comes to the surface, and they may take the form of bread-crust bombs of decreasing porosity, exploding magma-masses forming nuées ardentes, or a comparatively gas-free material from lower down may extrude as domes or spines or even as viscous flows. The phase of maximum explosive violence, although usually occurring at or near the beginning of the outburst, may be variable in time between wide limits that depend upon the length of the period of accumulation and the conditions to which the various sections of the magma column had been subjected during that interval.

It is most important to note that in such cases the ejected magma—except for the inevitable inclusion of the materials of obstruction and of cone disruption—will be contemporaneous, and that although the frequently repeated statements regarding many eruptions of this class—for example, that of Vesuvius in 79—that there was no "lava," may be exact as regards true effusive phenomena, they are misleading as conveying the impression of the absence of active magma. Although nothing absolutely prohibits an outburst in which the magmatic material, even if it furnishes the explosive element, lies too deep for its own ejection at that time, this will be an exception that does not invalidate the rule that *gas is the active agent and the magma is its vehicle.*

But a moment's thought shows how different will be the condition of a magma, especially in the upper portion of the conduit, when the conduit is open and free from all obstruction except that of the atmosphere—a condition normal to Vesuvius in modern times and one that prevailed for the thirty-one years from 1875 to 1906. In this case, whatever may be the physical condition of the deeper materials, that which occupies the upper portion will have been the channel of a continuous upstreaming of gas with heat-carrying and exothermally reactive properties, and with powerful churning and stirring effects, all of which, in spite of exposure to radiation and conduction and loss of heat through gas-expansion, will maintain the crateral and subcrateral magma at a high temperature.

Inasmuch as the gases are free to escape, there is normally maintained near the surface only a sufficient excess pressure over that of the atmosphere to result in a continuous effervescence of the mass, with occasional irruption of great high-tension gas-bubbles producing mild explosive effects. So nearly perfect is the state of equilibrium between gas-tension at the magma surface and the weight of the atmosphere that any variation of the latter reacts upon the rate of gas evolution with noticeable increase or diminution of the volcano's activity. This is especially noticeable at Stromboli.

But if this freedom of gas-emission prevails throughout the upper layers, such is not the case below, where pressure of the superincumbent material progressively increases with depth until a condition is reached which, as regards the retention and accumulation of gas, is *almost equivalent to a closed conduit.* In other words, the open-chimney condition produces, in time, a potentially explosive magma in the *lower* portions of the conduit, which will be *last* in coming into external manifestation during the course of an eruption.

We have thus a sort of standpipe whose contents may be considered as divided into a number of zones with downwardly increasing gas-accumulation, each subjected to a pressure that imposes a state of equilibrium and renders its explosiveness latent and proportionate to its depth.

Under such conditions the magmatic column, although occupying an open conduit, is as a whole potentially explosive, and all that is required to cause a great eruption is the intervention of some factor that is capable of disturbing the existing state of equilibrium.

Such a disturbance might be brought about in various ways, but inasmuch as the volcanic standpipe has been built up to a considerable height above the surrounding surface and within comparatively fragile containing-walls, the simplest contributing cause would be such a fracturing of the volcanic edifice as would result in lateral outflow and drainage sufficiently rapid and copious to reduce materially the level of the liquid in the tube. This, by relieving the pressure upon subjacent zones, will result in reactive gas-release, with expansional rise of material to a higher level, which in turn extends downward the condition of relief, with corresponding reaction in zones of greater pressure and power of gas-concentration. This progressive process of expansion, rise, and expulsion will continue—with concomitant destruction of the now unsupported terminal cone structure—until the

paroxysmal liberation of gas from the surcharged lower layers culminates in the outbreak and exhausts the accumulation of energy and material, so that there supervenes the cyclical interval of repose and renewal.

The time-periods in this succession of reactive impulses will depend upon the height of the column, the viscosity of the material, the amounts of energy set free in the various zones (in all probability rapidly increasing with depth), the mass of material in expansion, etc., and (providing the magnitude of these factors in such a case as we are considering is fully appreciated) the reader will not be surprised at the imposing span of these undulations.

We may now proceed to review the various phenomena of the eruption in the light of this theory of its mechanism.

At the commencement of April 1906, as shown in the "Narrative" (p. 33), the accumulative processes of the long active period that had begun in 1875 had finally built up to a high level a column of magma with retention of gas in proportion to depth, and thus potentially in a condition of paroxysmal explosiveness. The various lateral outflows of 1881–83, 1885–86, 1891–94, 1895–99, 1903–04, with their sluggish (p. 14) mound-building processes, could not bring about that rapid lowering of the magma column which is essential to active subjacent gas-release—even if a sufficient degree of saturation had been reached—while the rapid subterminal flows of 1905 (p. 24) constituted virtually only an overflow from the top of the column and were therefore incapable of affecting its height.

The weakening of the containing-walls could under these conditions be effected by various influences acting singly or together, such as increased irruption of great gas-bubbles acting against the inertia of heavy liquid and restricted vent, solution of inclosing-walls by thermal and chemical attack, disruption, through hydrostatic pressure, of the high magma column, etc. By some or all of these means fissuring occurred on the morning of April 4 in the southern wall of the cone and at a high altitude (1,200 meters) with at first a sluggish subterminal outflow. This was followed by downward extension of the fissure and a more rapid effusion, which effected the first true lowering of the lava-level, as is attested by the cessation of the northwest subterminal flows (p. 25).

It is important to realize that while this main causal factor—the rupturing of the containing-walls—is brought about directly by the above-mentioned processes, these are themselves the results of profounder conditions in the generative system of the volcano and may even be influenced by such cosmic forces as luni-solar gravitational stresses (p. 69). Although the accident which precipitates a paroxysmal outbreak may seem to be local and superficial, and however true it may be that gradual accumulation and upgrowth are essential to the scheme of final eruption, the real determining factor lies deep in the volcanic generator whose ability to furnish gas constitutes alone the true agent upon which all the eruptive processes depend.

As was recounted in the "Narrative," there followed progressive lowering and augmentation of the lava outpourings, with corresponding reactive explosive manifestations, illustrating in the most convincing manner the mode of action here set forth.

We must now consider an important feature of the eruption, the mechanism of which is somewhat difficult of definite explanation. During the night of April 7–8 the towering crater-cloud—now approaching its culmination and consisting of cone debris mingled with incandescent material of the paroxysmally expanding magma—began to send an inclined jet to the northeast over the crest of Monte Somma and in the general direction of Ottajano, carrying devastation to that town as well as to San Giuseppe and the adjacent villages.

From the Observatory the jet was seen to be luminous throughout its visible trajectory—i. e., as far as the Somma crest—but the ejectamenta lost sufficient heat in transit to do no more than ignite some dry straw in the vicinity of Ottajano. The presence of a large quantity of non-luminous detritus was attested by powerful electrical phenomena, and discharges were observed to strike the crest of Monte Somma. At Ottajano several buildings were struck, and balls of fire were seen to touch the ground and then disappear, from which we may possibly infer the phenomenon of globe-lightning, although this was not observed at any time within the crater-cloud.

The maximum depth of the fallen material at Ottajano was from 80 centimeters to something over a meter in open spaces, with drifting to a greater depth. Under the weight of this material many of the flat roofs collapsed and most of the victims of the eruption thus lost their lives, one hundred and five having perished under the falling roof of one church at San Giuseppe. The total loss in this sector was two hundred and twelve.

The ejectamenta comprised fresh lava scoriæ of a light-weight, highly vesicular, vitreous type, and old, altered, and oxidized nuclei enveloped in fresh material, as well as ash in differing grades of coarseness. But perhaps the most characteristic product was a comparatively dense, though vesicular, dark lapillo with rounded contours. This appeared to be fresh, but was either not contemporaneous or else a product of the specific condition of one particular part of magma then in process of effervescence and expulsion. The problem of its origin is undoubtedly linked with that of the mechanism of the inclined jet itself, and, in view of the possibilities of local magmatic solution and digestion, the writer is inclined to believe that slight differences in the proportion of ingredients, as revealed by chemical analysis, are often too lightly accepted as guides in determining the physical processes of an eruption. This point is further considered in the section on the "Solid Ejectamenta."

As to the mechanism of this inclined jet, there has been considerable diversity of opinion, notably centering about the depression in the north-northeast rim of the crater—the "échancrure"—which has been considered by some as cause and by others as effect. Mercalli spoke of this as "a sort of loophole which directed the projectiles of the volcano in that direction." Jaggar[1] says: "The volcano probably partly dammed within by welling lavas on the Bosco side, vomited its earthy jets obliquely outward on the opposite Ottajano side." Others have considered the main volcanic conduit to have been inclined in a northeast direction, etc.

[1]Jaggar (1), p. 112.

In investigating the cause of this jet, several facts should be borne in mind:

1. Its duration was limited.
2. The oblique jet was but a portion of the column, the main body of which maintained a vertical position, throwing its projectiles in many directions, e. g., southward (to Casa Bianca, 3.5 kilometers) and westward (to the generating-station of the Vesuvian railway, 4 kilometers).
3. Precisely the same phenomenon has occurred during a number of past eruptions (e. g., 1649, 1737, 1779, 1847), but not in many others of equal violence.
4. Finally, the preeminent fact of the main Vesuvian eruptive fissure lying in a general north-south direction with tendency to northeast-southwest obliquity at the surface, and with southwest migratory tendency in depth, and with general northeast-southwest seismic throw.

The significance of the first fact lies in the testimony to the dependence of the obliquity of projection upon the position in depth of the source of emission. The inclination ceases with the progressive voiding of the conduit, and this raises a point which has long impressed me as constituting a specific factor in the mechanism of volcanic eruption. I term this the *level of explosion*, i. e., the level, variable in altitude, where expanding gas bursts from the magmatic bath. When the magma column is in direct contact with the atmosphere, this explosion level will be the top of the column, but when the top of the liquid column is deeply buried under a mass of cone debris the condition is complicated by the retention of the expanding gas-bubbles and their final escape from the upper layer of this chaotic accumulation. But the true seat of emission—the explosion level—will still be the head of the magma column, and the importance of knowing the height of this will be obvious. We shall again refer to this in our study of the "Intermediate Phase"; but the appositeness of its recognition in connection with the limited duration of the inclined jet lies in that, inasmuch as the descent of the explosion-level into the vertical conduit-tube put an end to the obliquity of the projection, we may infer that a superficial and temporary conformation or deformation of the upper edifice may really have been at the moment a determining cause of inclination.

As to the second fact, the writer as an eye-witness can testify most positively. The visible impression was that of a deflection from the vertical of one side of the "smoke" column. This could result from an obstacle, as by touching one side of a fountain-jet, or from a profound collapse of the cone-terminus in one azimuth while in others it remained for the time intact.

The existence of a similar obliquity of projection during a number of past eruptions is most significant and strongly points to some specific configuration or characteristic of the volcano as the principal determining cause. In regard to this we may consider (1) the fact that the main cone has its south and west walls massively constructed and strongly braced with lava dikes and sills, while its northeast walls are, instead, composed almost wholly of friable materials, (2) the Monte Somma ridge on the side of the inclined projections, and (3) finally, the point of our fourth consideration—the subterranean meridional fracture whose existence is so frequently in evidence.

In connection with these conformations we may imagine several modes of action which might result in oblique projection. For example: (1) The Monte Somma ridge, forming with the Atrio an elevated plateau, may so obstruct aerial updraft and even produce such an aspiration as to induce an inclination of the column toward that side (it being admitted that eruptions have occurred without this inclination); (2) the early collapse of the weak northeast wall, while the opposite side would be left intact; (3) the tendency of the subterranean fissure to migrate toward the southwest, causing the undermining of the wall of the conduit, whose resistance would deflect the rising jet northeastwardly (with the admission that this would probably affect the entire column).

The writer is inclined to believe that the famous "échancrure"—considered as the depression remaining in the rim of the crater after the eruption—was not related, as either a cause or an effect, to the production of the oblique jet, but that

Fig. 45.—A short, broad lava-flow below the north-northeast rim of the crater; probably the cause of formation of the échancrure.

the mechanism of its formation was nevertheless contributory. The fissuring of the crater-wall in that direction, with outflow of lava (Fig. 45), caused a collapse of the upper northeast rim, facilitating obliquity of projection in that direction, with probable contact-deflection by fallen material and a deformed vent. It should be remembered that this interval of time, although generally called the culmination of the eruption, was so only as regards seismic manifestation and the emission of incandescent lava. The beginning of the true explosive maximum with paroxysmal emission of gas coincided with the cessation of the oblique jet and the recession of the explosive level into the depths of the conduit.

As contributory factors, several of the above-mentioned permanent features may have influenced the result, while the possibility that a similar process of cone-deformation had occurred in the past may not be remote. Reproduction of conditions is exceedingly common at any volcano that is normally active and with

periodic and homogeneous eruptive habit, and we may thus account for both the occurrence and non-occurrence of this inclined projection in the past.

Before leaving the subject, there may be mentioned an interesting detail concerning the fall of lapilli at Ottajano. Most of these were deflected, before coming to earth, by a strong lower wind blowing toward the volcano—a counterpart of the updraft experienced by us upon the southwest flank, but more powerful because of the aspiration of the overarching jet. Many of these projectiles thus struck the glass of windows on the farther sides of houses, and a considerable controversy has arisen over the fact that many panes of glass were broken in such a way as to leave more or less perfectly circular openings (Fig. 46). Such perforations are fairly common, and the writer photographed a window in the Messina post-office after the earthquake of 1908 in which a circular opening had been produced, evidently by a fragment projected from the opposite wall (Fig. 47). The writer believes that they were produced by simple diagonal percussion.

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Fig. 46.—Circular perforations of window-panes at Ottajano; photograph published by Sabatini.
Fig. 47.—Circular perforations of window-panes at post-office of Messina.

Returning to the eruption and its mechanism, the writer as an eye-witness must insist upon several points which conflict with statements made by others. It was not until 3^h30^m a. m., April 8, that the grand break-up of the mountain-top took place, and this process continued until 4 a. m., when the final, deepest gas-liberation began the paroxysmal "blowing-off" which constituted the "Intermediate Phase," soon to be considered. The strong seismic shocks of 0^h37^m and 2^h30^m a. m., April 8, were not, therefore, caused by the fall of cone-masses, as indeed would seem evident from the fact that the earthquakes had been strongly felt at Naples, but were due probably to a profounder cause, as discussed in the "Seismic Section" (p. 81).

The breaking-up of the mountain top was indescribably spectacular, and if any phase of the great culmination was awe-inspiring it was this. Its mechanism

was undoubtedly that of detachment and downfall, but not in the manner nor to the extent generally supposed. The reader is asked to realize that, in the eruptive phase now under consideration, "explosion" is a continuous process; that is to say, there is no sudden outburst pushing upward directly against an air-cushion, but, instead, a rapidly recurring series of explosions, often many to the second, follow each other upward so as to form a continuous jet. The power had now become such that the material collapsing from the top and sides of the chasm was caught up and vertically projected with ease, and thus the effect, viewed externally, was that of an *outward unfolding* of the mountain-top, with progressive widening and lowering of the crater. This process largely subsided shortly after 4 a. m., probably with the clearing of the entire upper conduit to the full diameter of the original magma column, thus leaving no further overhang of material.

The admixture of this great mass of cone debris had greatly darkened the crater-cloud, whose incandescence, however, had already apparently diminished considerably, although by this time daylight had intervened and rendered the observation uncertain; in fact, this most interesting phase was begun, continued, and ended within the hours of daylight. The writer remarked at the time that we might yet be obliged to admit a lower temperature in the deeper magma than in the contents of the crater, unless expansion and comminution, together with descent of the explosion level to a great depth, might explain the apparent lack of luminosity.

In the early morning of April 8 that remarkable period of transition connecting the luminous first period with the dark, ash phase of the third period was fairly begun—that great explosive culmination which the present writer insists upon considering a specific manifestation of the eruption, perfectly distinct *per se*, although merging into the others at either end. Its chief characteristic was the paroxysmal emission of gas. Although considerable ash was present and although blocks and fragments of dikes torn from the conduit-walls, as well as ancient and even non-igneous masses from the depths, were continuously ejected, the overwhelmingly predominant product of emission was gas. This issued from the now unobstructed conduit-tube under very great pressure and with enormous velocity, reaming out the throat of the volcano into a cylindrical section (Fig. 31) and reaching to a height of 10 to 13 kilometers. There the compressed gas, carried very rapidly to that elevation, expanded outward with indescribable velocity against the surrounding air-cushion to form exquisite cauliflower heads, like carded cotton, whose sharply defined contours—the ash having been screened out and left behind—showed the perfect whiteness of condensed steam.

The writer knows of but two hypotheses to explain the origin of this gas, the first of which is here given more for the originality of its conception than for any probability of its truth. It is due to an author whose name is unknown to the writer, and it might be called the "gas-pocket hypothesis." This hypothesis presupposes a migration of the eruptive forces from an old conduit, which had been obstructed above, to a new channel which now constitutes the active vent, with the two in communication at a certain depth, the arrangement being analogous to the compression-chamber of a force-pump. Ascending magma fills the opening between

the two, compressing the gas in the closed chamber and rising and accumulating in the other. When this is voided by external eruption and the magma-level is again lowered to the intersecting point, the vapors compressed in the closed pocket escape through the conduit and produce the paroxysmal gaseous phase.

Nothing precludes the possibility of such a mechanism. But the reactive emission of gas, after relief by lava-ejection, is general—one might say universal and even inevitable—when the proper conditions are fulfilled. Are we then to suppose that such a convenient gas-chamber has been formed within each volcanic edifice? There is no need to do so, and what seems to me to be the preferable explanation is as follows: The lower magma, surcharged with gas through accumulation under pressure of the superincumbent lava column, is a sufficient source of gas when the escape of this is possible. We must suppose that the "explosion level" gradually descends into a magma which is very different physically from the liquid which had occupied the upper part of the conduit. Such a magma would more closely resemble that of a volcano with a closed conduit (p. 59). This magma would form not a liquid lava in which the dissolved gas coming out of solution would vesiculate the entire mass, but an exceedingly dense and nearly solid paste incapable of rapid movement of its mass, the explosion of the gas in which, although potentially very violent, would take place largely at its surface. It might be compared, provided that all idea of combustion be excluded, to the "burning-off" of a rocket-mixture in its case.

The material will thus be pulverized, and, although abundant, the amount ejected will be small in proportion to the quantity of gas, and the production of the resulting ash will be simultaneous with the outrush of gas except for a certain quantity torn from the conduit-walls. As we shall see in the section on "Solid Ejectamenta," it is precisely the comminuted material of this phase which most conspicuously shows that it is derived directly from the magma.

There thus prevailed for the time a condition in which the downward progression of the level of explosion will have been more rapid than could be compensated by the slow expansion of the almost solid magma, but the maximum depth to which the explosion-level descended is not known. Simultaneous seismographs at the Observatory and at sea-level might have shown this by resolution of their components, but we have only estimates, given rather loosely, as the "maximum depth of the crater during the eruption," and reaching 1,000 meters (Matteucci). This estimate, which would bring the explosion-level to within 200 meters of the sea, has seemed excessive to others, but certainly not to any near witness of the paroxysmal blast of gas. This, with a diameter of at least 400 meters at point of issue, shot upward with so little lateral spreading that at a height of 12 kilometers the edge of the globe-topped gas-column was still scarcely more than vertically overhead 2.5 kilometers from the volcanic axis. A very considerable length of bore and enormous acceleration would seem to be required for the column to have attained this height, so that it seems to the writer that the assumption of a temporary descent of the level of explosion down to or below sea-level is quite admissible.

This phenomenal descent of the level of explosion must have been of brief duration. In this lowermost zone of surcharged magma, representing the chief reservoir of accumulated energy, there had supervened, by nightfall of April 8, the beginning of approaching exhaustion. With diminished rate of emission the explosive process no longer, so to speak, ate its way downward, but in all probability rose with the slowly expanding magma, whose volatile elements now began to cope anew with cone debris, the downfall of which into the abyss was no longer effectively opposed by the weakening blast. We may suppose the rise to have continued until a condition of virtual equilibrium in height was established between the magma, still voluminously evolving gas, and the downwardly pressing piston of dead material from above.

That this final level of equilibrium was well above the greatest depth attained during the "intermediate phase" seems extremely probable, and inasmuch as the top of the obstructing-plug in the conduit at the end of true activity (May) was invisible from the crater-rim—and therefore at least 400 meters below—we may infer the final altitude of the active magma column as dependent upon whatever vertical thickness we may assign to the obstructing plug. If we assume this thickness to have been at that time 200 or 300 meters the magma-level at the close of the eruption would have been from 600 to 500 meters above the sea. This altitude, considered as a maximum, and in view of such facts as the post-eruption beginning of primary fumaroles upon the outer flanks of the cone, may be accepted as a rough approximation.

With the setting in of the third period of the eruption (the "dark ash phase") the process again caused powerful isolated explosions. The magmatic gases no longer discharged directly into the atmosphere, but were retained below and within the obstructing mass of detritus until the increasing volume and tension could overcome its resistance, with resultant dynamic effects which, reactively, caused the dislocation of further material. But inasmuch as this mode of action (although it prevailed through the longest period of the eruption) involves no new feature of mechanism, we may feel privileged here to close this section, especially as many of its processes will again be viewed, from a different angle, in the chapter on "Explosive and Seismic Phenomena."

The mechanism of the eruption may thus be concisely considered as a paroxysmal release of energy accumulated under and within the volcanic edifice during a long period of slow supply of magma from below, and proceeding in a series of rhythmic pulsations due to reactive discharge of gas from underlying magma relieved of pressure by rapid lateral drainage of overstanding material. The dynamic value of each magmatic uprise and discharge increased as the lower and more intensely saturated layers went into action, culminating on the fourth day in truly catastrophic effects, with subsequent gradual decline, this period being lengthened because of progressive suffocation of the still expanding volatile material by means of detritus and debris collapsing from the ruined structure.

An interesting detail of mechanism is the variation in the proportionate amount of liquid and solid material entrained by and ejected with the escaping

gases during the various periods of the eruption. At the beginning of the lava phase, the dissolved gas, in coming out of solution and in vesiculating the liquid, carried out with it very great quantities of solid material both effusively and explosively. With the gradual voiding of the contents of the conduit and the coming into action of more highly explosive magma, the gaseous element was constantly more in evidence, and the culmination of the eruption revealed a maximum of the volatile element and a minimum of fragmental ejectamenta. This condition again reversed itself with the progressive exhaustion, until again the propulsive gaseous emission became laden with solid matter almost to the point of saturation (Fig. 40), although now with the finer products of subdivision.

LUNI-SOLAR INFLUENCES.

Paintings of great Vesuvian eruptions frequently show the moon at its full serenely presiding over the stirring scenes of earthly elemental strife. Although art may feel privileged arbitrarily to introduce that which might add impressiveness to such a spectacle, still it would seem that these representations of our satellite were really prompted by the nobler motive of depicting what was seen, and thus permitting the graphic presentation to be not only beautiful but true. It thus behooves the scientist to seek and find the cause of a coincidence too frequently recurring to be called fortuitous. But it will be found far less difficult to demonstrate that some influence actually is exerted upon the eruptive processes of volcanism at times of favorable luni-solar positions than to give an explanation of the precise mode of action.

Coincidence, as has been said, is often noted. Palmieri frequently called attention (and was ridiculed for so doing) to important events, such as the beginning of lava streams having occurred at the time of full moon. Riccò examined a series of outbreaks at Stromboli, concluding definitely that luni-solar influence was clearly demonstrated in a majority of the cases, and he added the example of the submarine eruption at Pantelleria in 1891. In a later note he also found evidence in support of similar effects at Etna. Schmidt[1] and Falb[2] studied the influence of luni-solar positions upon the earthquakes, with conclusions favorable to the thesis.

The present writer has, from his very first experience, been impressed by the reasonableness of an influence so in harmony with the intimate inter-relationship of central-sun and earth-moon system. It is a fundamental geophysical process which is affected in its workings by the powerful stress variations that result from the rapidly changing relative positions of the three heavenly bodies concerned; and he has felt convinced that great benefit would be derived from study of the subject, providing always that exaggeration be avoided, and the process recognized as constituting an influence upon, rather than the cause of, volcanic manifestation.

After the revelation of the Vesuvian eruption (see "Dynamic Curve"), Stromboli, in 1907, showed remarkable coincidence of explosive crisis with the syzygies, which the writer embodied in a curve whose practical utility was demonstrated in

[1] J. F. J. Schmidt, *Studien ueber Erdbeben*, Leipzig, 1875.
[2] R. Falb, *Grundzüge zu einer Theorie der Erdbeben und Vulkanausbrüchen*, Graz, 1880.

the course of the eruption. In the following year he published a paper[1] setting forth a tentative method of graphic representation of this influence, based upon arbitrary values for the various positions. This was expressly stated to be a crude and incomplete effort, brought forth in order to stimulate criticism and further research, but it has served—through the many recognized correspondences—to demonstrate the effectiveness of celestial influence in determining the dates of terrestrial volcanic maxima.

A full discussion of the subject (involving the citation of many astronomical and volcanological data) is at present impossible, nor is it probable that our knowledge is as yet sufficient to elucidate the matter fully. Enough may here be said, however, to set forth the general proposition and to show that a very real practical advantage accrues to the investigator from a consideration of astronomical data in connection with his work in the field.

It is natural to consider the effect mainly from the gravitational standpoint, and the well-known phenomenon of the moon-begotten tides suggested to earlier investigators a perfect analogy in the then supposed liquid globe with tidal movements under a thin crust. Nor does the concept of a solid, or rather rigid, earth eliminate the gravitational idea, for with it has come a realization of the intensity of the deforming stresses and actual instrumental measurement of the resulting solid tides.

We may venture, therefore, to consider the luni-solar influence on the basis of a tendency to deform the terrestrial spheroid. The sun's gravitational pull upon the earth is intrinsically the greater; but the moon, through its proximity, exerts a greater *difference* of attractive power upon the near and far sides of the earth, thus producing a deforming stress which has been calculated to be 2.5 times greater than that of the sun.

The writer would call attention to an astronomical fact not always recognized, although it constitutes an important element in the accentuated variations of stress we are considering, namely, the uniqueness, among the planetary groups in our solar system, of the earth-moon couple as regards the relative masses of its components. In all other cases of planet and satellite, the latter has little mass relatively to its primary, and revolves around the planet with but slight oscillation about the common center of gravity of the system. Whereas, in the case of the earth and moon, the relative proportions are so much more nearly equal[2] that the couple virtually assumes the status of a stellar binary, the center of gravity of which, while still within the earth's circumference, is yet far from its center.

There are thus, including the sun, three gravitationally interrelated masses, all intrinsically powerful as stress producers, the orbits of which bring two of them alternately in line and at right angles with the third. The variations in deforming stress to which the earth is thus subjected will depend upon the conjoined luni-solar influences when in conjunction or opposition and the more or less complete neutralizing of the one by the other when in quadrature.

[1] F. A. Perret, *Science*, August 28, 1908. [2] The diameter of the moon is 0.27 of the earth's diameter.

The degree of deforming stress exerted upon the earth is also subject to considerable variation by a number of factors, such as relative distances, angles of position, perihelion, and perigee, the last being very powerful through its large coefficient of variation with apogee.

In a general way the conditions which result in the greatest deforming stress will be those which produce the highest ocean tides, viz, the syzygies, perigee, perihelion, and zero luni-solar declination. But it would be inadvisable to base our deductions entirely upon liquid tidal effects, and observation seems to show that, for our latitudes, the maximum north-south declination of sun and moon is more effective than the equatorial position. It should be noted, however, that the luni-solar positions under which the culmination of the eruption of Vesuvius occurred were those that produced the highest ocean tide of the year. Modern measurements of the solid tides may possibly throw light upon this point.

It is difficult, with our present knowledge, to arrive at a conclusion which may be considered as proved as to how these stresses react upon the processes of terrestrial volcanism. During the earth's rotation, each meridian daily passes twice under the powerful stresses of opposition or conjunction and twice under the weaker ones of quadrature, and it seems probable that—unlike the liquid tides whose lag is often many hours behind the lunar transit—the volcanic response is prompt, in spite of magmatic viscosity. Midnight and midday at full moon almost invariably bring a noticeable increase of eruptive activity, and in this, as well as in other cases of response, promptness is the more marked when volcanic activity is already under way, i. e., during the course of an eruption or of an active period. There will frequently be found a slight lagging behind the phase in an outburst following a period of obstruction, or in the last efforts of the volcanic forces approaching exhaustion toward the end of an eruption, while, on the contrary, a rising eruptive phase culminates before the maximum influence is exerted, as in the present eruption.

It would seem, therefore, that, although the profounder magma masses are probably not unaffected, only the more superficial accumulations would be able to show the prompt external response which is observed—those internal and subjacent reservoirs of the volcano itself whose amassed energy and materials alone, in all probability, go into action during an eruption.

Everything points to the luni-solar influence being indirect, in the sense of releasing energy already stored, and this feature explains the passing of favorable dates without result at any given volcano where the conditions have not, at the time, been such as to permit of response. In analogy with a gun which, although loaded and primed, will not "go off" until the trigger is pressed, this indirect action has been often spoken of as a "trigger effect."

At first thought there would seem, it is true, to be nothing incredible in the hypothesis that a deforming stress which actually produces a solid terrestrial tide of 50 centimeters at the equator and 30 in our latitudes should, by the compression of a magma-filled pocket or fissure, force lava upward to a higher level in a volcanic conduit, with resultant increase of external activity.

But viewing the conditions in correct perspective—with this given elongation of radius or expansion of circumference extended over a distance enormous in comparison—it is difficult to conceive of any relative motion between walls, blocks, or strata that are contiguous. There would seem to be required some sharp difference of effect at the surface layers (something analogous, even if but remotely so, to the superficial free-motion wave of earthquakes), as though the uppermost strata were lifted, so that the greater proportion of radial elongation would take place near the surface. In other words, the measurable solid tide would be largely superficial.

Postulating this, we may imagine a condition of uplift throughout the upper crustal mosaic, with temporary lessening of the centripetal pressure, thus permitting expansion of the masses of magma, with consequently augmented facility of gas-evolution.

The writer is aware that many attribute the rise of magma to the downward pressure of solid materials having the greater density, but he is also convinced of the error involved in considering the magma as a simple inert liquid, which conforms in all respects to hydrostatic principles. On such a basis, an area of strong barometric pressure prevailing over the region of an open-conduit volcano, such as Stromboli, should theoretically tend to elevate the lava column and increase the activity, but the reverse is invariably the case, and it is through the supervening of low atmospheric pressure that gaseous emission is renewed and the eruptive process is resumed.

Volcanic magma being a container of gas under pressure, its expansiveness and consequent centrifugal tendency are opposed by the centripetal force of terrestrial gravitation acting upon its solid retainer, and any lessening of the centripetal pressure by counter-attraction from without must inevitably result in the dilation of the potentially active material. Charged magma is a cubic spring.

From the possible causes of volcanic response to the luni-solar influence we may exclude magnetic, electric, thermal, and atmospheric agencies because of the absence of instrumental indication. Whence, in the present state of our knowledge, it would seem that we can postulate only a gravitational cause, and in particular (for the reasons given above) a more or less superficial uplift and relief of centripetal pressure, with relatively increased release of the potentially active and expansible magmatic gases.

Nor need we exclude all idea of action in the sense of an upforcing of the magma column, or at least a tendency which, through the stiffness of the material, might result in rupture of the cone. For if the syzygies constitute astronomical maxima, as regards their effect, the more or less complete neutralizing of this factor by the cross-positions of quadrature may be regarded as constituting terrestrial maxima—i. e., a condition where the earth's own centripetal gravitation is restored to its greatest power. This would mean increased pressure upon masses of magma by their solid containers, with resultant tendency to force the magma upward. We might even imagine the alternation of the two effects as resulting, so to speak, in

a sort of pumping action, the magma being squeezed upward by the pressure due to quadrature, and being maintained there through its expansion under the relief of these by the influence of the syzygies. We would thus have an additional cause for the rise of magma from the depths. Quadrature, for these reasons, has seemed to the writer to be the more effective controller of earthquake dates.

However this may be, and to whatever extent this hypothesis may eventually be found to approximate to the exact *modus operandi* of the luni-solar influence upon volcanic activity, the actual results are beyond question. In the observational study of an eruption or a period of minor activity, a plotted chart of this influence constitutes, for the writer, a veritable time-schedule of probabilities. For example, in Section IV, on "The New Active Period," it will be seen that the writer's various descents into the crater were planned to yield the most fruitful results by coinciding with powerful luni-solar maxima. At Stromboli, during four great eruptive phases, advantage was always taken of the maxima to be ready with instruments at observational vantage-points and of the minima for visiting desirable, interesting, but dangerous localities. At Etna, in 1910, the eruptive fissure, with its twenty-four active craters and 2 kilometers of length, was safely crossed during a luni-solar minimum, and Professor Oddone appeared one day at the writer's hut, laughingly announcing that he had "come from Rome to be present at the coming luni-solar maximum"—and he was not disappointed in its effects. But it would be tedious to enumerate the many instances that prove the general utility, in research work, of this powerful factor of control over the times and seasons of the principal manifestations of energy.

Wood[1] has criticized the writer's method of plotting the curves of this influence, and has proposed a system based on the more prolonged effect of nutation, which gives as maxima the solstitial positions and as minima the equinoctial. This was conceived when the functioning of Kilauea seemed to indicate correspondence with this more essentially solar influence, but that this was fortuitous or inconclusive is shown not only by many equinoctial approximations elsewhere—including Vesuvius (April 4)—but by the subsequent behavior of Kilauea itself, of which the most recent demonstration was "the sudden rise, violent ejection of gas, tumultuous cauldron action, and coincident seismic spasm," which Jaggar does not hesitate to call an "eruption," and whose climax was at the equinox (March 1921).

Neither Wood's nor Perret's method of computing curves to represent the times of principal luni-solar influence is of any precise value as a "system." So far as the writer is concerned, it was intended "to stimulate the criticism of others in order that the truth may be the more rapidly advanced." But it will require much time and long observation at many volcanic centers before the laws which govern this action can be definitely formulated, and in the meantime the practical application of a method, although imperfect, is the best means of determining its defects and of acquiring knowledge through experience.

[1] H. O. Wood, *Cyclical variations in eruption at Kilauea*, Second Rep. Hawaiian Volc. Observatory, p. 6, 1917.

THE FLUENT LAVA.

Inasmuch as all the fluent lava of this eruption was ejected during the first four days and proceeded from the one magmatic reservoir within the volcano, the streams that were emitted from the various vents showed very slight variation in chemical composition.[1] Mercalli[2] mentions a preponderance of leucite phenocrysts and scarce megascopic augites in the slow lava outflows up to April 4, and precisely the contrary in the rapid lavas of the eruption; he points out as a cause the recent rising of much of this material and its brief sojourn in the throat of the volcano. The physical characters were apparently dependent more upon the location of the vent in altitude than upon any considerable difference in temperature, although the extremely vivid incandescence of the last liquid material ejected in large amount during the culmination of April 7 and 8 showed this lava to have had a higher temperature than that of any of the previous flows.

The first small lava streams on the south side of the summit on April 4, at an elevation of 1,200 meters (A, Plate 1), were comparatively sluggish, being little more than overflows from the top of the magma column. But the progressive downward extension of the fractures gave increasing impetus to the emitted liquid and, with the opening of the Bosco di Cognoli vents at 600 meters altitude (D, E, F, Plate 1), the lava was ejected with a velocity of not less than 5 meters per second, and under a pressure sufficient, at times, to enlarge its vents by rending open the solid rock (p. 39), and even to result in powerful fountaining of the liquid for a brief period during the night of the culmination.

It is customary to invoke here the "hydrostatic" pressure of the lava column, but the writer must insist that this be made conditional upon the recognition of other factors. A moment's reflection will show that no such pressure as that which would result from a superjacent column of 500 or 600 meters' elevation was actually transmitted to these vents; no surface rock could have continued to roof the tunnel carrying a liquid under such pressure.

We assume, therefore, a mechanism which also conforms to the exigencies of other observed phenomena; this, by analogy with the delivery-cocks of high-pressure gas-tanks, may be called the "reducing-chamber." The injection of liquid magma into the interstices of a ruptured cone will tend to widen and extend the apertures in all directions, mainly through the formation of dikes in the vertical fissures, but also by formation of sills between horizontal strata. These will inevitably be irregularly distributed and, because of the tortuosity and narrowness of the other fissures, will so reduce the effects of the gaseous energy and the rate of flow as to bring the lava finally to the surface with a diminished velocity and copiousness of emission that may be paroxysmal but is not necessarily locally catastrophic. The writer thus explained[3] the apparent discordance between powerful internal dynamic effects and a surface eruption of the most moderate order at Teneriffe in 1909. But the emission of such rapidly flowing lava forms, nevertheless, an impressive

[1] Cf. A. Lacroix (5).
[2] G. Mercalli (3), p. 22.
[3] F. A. Perret, *The volcanic eruption at Teneriffe in the autumn of 1909.* Zeitschr. Vulkanologie, I, 25, 1914.

and instructive spectacle, and the outflow at the main vent of Bosco di Cognoli (Plate 5) was as rapid as any that the writer has ever witnessed.

The emission of vapor from the surface was continuous and powerful, but regular and without true explosiveness, evidently because of non-coalescence of the vesicles of gas. The conformation and operation of the volcano's eruptive apparatus, considered as a whole, were such as to effect that complete separation and segregation of the explosive and effusive phenomena which are most characteristic of this type of eruption—the gravitational adjustment by which the great gas-bubbles rise through the main chimney and issue explosively from the crater, while the heavy liquid drains off through lateral vents, with its remaining gas coming out of solution in tiny vesicles, which have collectively considerable dynamic potency, but which are incapable of great explosive manifestation because of their individual minuteness.

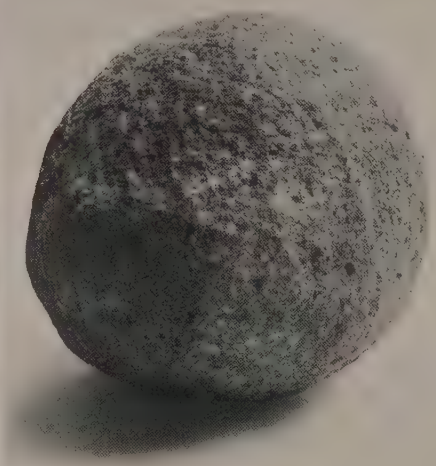
If it were not for the inadvisability of further complicating volcanological phraseology, it would be possible to provide a decimal scale of values to indicate the gradations through which the extreme aa characteristics become attenuated and merge into those of pahoehoe, with an almost equal-spaced subdivision of these. We may have, for example, a mass almost wholly of detached fragments;[1] or a flow presenting the appearance of a plowed field, so earthy and incoherent are its materials, and with "séracs" like the flexed portions of a glacier;[2] a coherent, massive core from whose advancing front fall blocks like bituminous coal, black without and red within, the center of the stream bearing masses weighing tons;[3] or an exceedingly rough and all but impassable flow, whose asperities are, however, united in one continuous monolith of granitic firmness.[4]

The Vesuvian lava of this eruption may be considered as one of the most common forms of medium aa (Plates 6 and 7), namely, a comparatively homogeneous but fully scoriaceous layer covering a mass whose very considerable degree of liquidity, even at a distance from the source, permitted it to descend to an almost surprising distance for a not ultra-basic lava. The fluent material followed even insignificant natural depressions, bifurcating and reuniting to leave "dagalas"[5] (islands) of untouched soil, following sunken roads and railways, leveling some houses, entering others by door or window,[6] and conforming roughly to the invaded space, but lacking that exquisite modeling to fine detail that is characteristic of Hawaiian and other very liquid lavas (Plate 6). Green trees showed, as usual, considerable resistance to the lava's heat, through the well-known effect of a non-conducting film. The "moraines" were comparatively small for lavas of such dimensions, but rapid flow down the center was an important characteristic. The area covered by these principal flows upon the southern flank (Plate 6) was approximately 3,000,000 square meters and the volume of material was 10,500,000 cubic meters. This would give an average depth of 3 meters. Adding the volumes

[1] Etna, 1908 (portions of flow).
[2] Teneriffe, 1909. [3] Etna, 1910. [4] Kilauea, local conditions.
[5] "Dagala" is the term used at Etna to denote patches surrounded by a flowing lava stream and left uncovered by lava. The corresponding Hawaiian term is "kipuka." (H. S. W.)
[6] See illustrations in Johnston-Lavis (4).

of the eastern and northern flows, and the small amount which continued to be emitted from the northwest subterminal vent until midnight of the first day, the total fluent lava output of the eruption would scarcely exceed 12,000,000 cubic meters.[1] There was no accumulation of material around the vents nor any attempt at cone-building, the lateral eruptive apparatus consisting of simple tunnel-openings with normally horizontal delivery-tubes. It was inevitable that such important effusive phenomena should transport foreign material, and "pseudo-bombs" of various types were to be found upon the lavas, the most interesting of which were the spheres of old lava wrought into shape within the volcano (Figs. 48 and 49). The fumaroles that developed upon the lava streams are considered in the narrative of the "Repose Period."

48



49

Fig. 48.—A "cannon ball pseudo-bomb" ejected during the eruption.
Fig. 49.—A "cannon ball pseudo-bomb" from the Bosco di Cognoli flow.

The small ephemeral lava-flow upon the upper northern slope of the cone formed a cascade self-arrested for want of material (Fig. 45), this being one of the reasons for supposing the unobserved phenomenon to have occurred during the final and almost momentary uprising of lava in the conduit during the night of the culmination. Its only importance lies in its having been the principal cause of the formation of the famous "échancrure."

The writer would again call attention to his observation of the small lava-stream which issued from the northwest side of the cone in consequence of the re-fusion of the surface layers (p. 27). This revealed a process which undoubtedly

[1] [Mercalli (1) estimates that 1,728,000 cubic meters of lava were poured out between May 27, 1905, and April 4, 1906. He thinks that the volume of lava emitted during the great eruption was much less than the volumes at the eruptions of 1794 and 1822, and estimates "very approximately" that the volume that issued on April 4–8 scarcely reached the 20,000,000 cubic meters calculated by Palmieri for the eruption of 1872, the Bosco di Cognoli flow having a volume of about 13,200,000 cubic meters. Sabatini (1), p. 1117, estimates the area covered by the lava-flows of the 1906 eruption at 230 hectares and their total volume at 5,475,000 cubic meters, of which 4,056,000 belong to the Bosco di Cognoli flow. The discrepancy between the sets of figures is great and illustrates the uncertainty that attends such estimates. H. S. W.]

holds an important place among the hidden operations of volcanic action and the nature of which is now becoming recognized. If its specific function has not earlier been realized upon Vesuvius—the most fully studied of volcanoes—this is certainly because of the great petrographic homogeneity of the modern (upper) Vesuvian edifice which permits of no very marked variation of the magma through absorption of re-fused material. When like dissolves like, no particular alteration of the original solution results therefrom. It is indeed precisely this quality of homogeneity which, at times, renders it difficult to determine whether a given product, such as ash, consists of old or new material. In other cases, when there occur magmas of different compositions, re-fusion may result in synthetic mixtures with more or less incomplete digestion, which afford clear evidence of the melting process.

The all-important question of the origin of the excess of heat is beyond the scope of the present work. We may consider as factors heat-carrying gas, gaseous interreaction and combustion, with contributory liquid convection, and the resulting possibility of higher temperature in the upper portion of the magma column, where such factors would exhibit the greatest activity. And this sets a limit to solution in depth which observation, as well as theory, seems to require.[1] Evidently powerful limiting factors intervene and prevent the destruction, by this means, of even the upper volcanic edifice. This suggests the existence of automatic adjustment, possibly through release and diversion of energy by other transformations. This is one of the most fundamentally important problems for future study.

THE EXPLOSIVE EFFECTS.

From the "Narrative" the reader will have gleaned the main characteristics of the explosive phenomena during the various phases of the eruption, which have been described in the discussion of "Mechanism," but their importance calls for specific consideration and examination in detail. The condition of the volcano at the outset was, it will be remembered (p. 61), that of a high magmatic column, its upward extremity confined within a terminal conelet recently built up through mild explosive activity, ending in an open crater that gave free communication with the atmosphere.

From the fact that no blocks of recently consolidated lava were ejected during the eruption, we may conclude that the crateral and subcrateral lava had re-fused and assimilated all that may have remained of a crater-filling "plug" or of a "plastic lining" in the conduit. In view of the recent kinetic and chemical activity of this lava-bath, we may even infer a progressive solution and consequent thinning of the crater-walls, with resultant hastening of their collapse.

We may consider the underlying magma as progressively changing, downward, into a gas-pervious mass saturated with vapor at enormous pressure (pp. 67, 80).

On the morning of April 4 (p. 34) the normal activity at the crater, with the usual emission of whitish vapors, was followed by a fracturing of the containing-walls and injection of dead, collapsed cone-material into the explosive circulation.

[1] G. W. Morey, *The development of pressure in magmas as a result of crystallization.* J. Wash. Acad. Sci., *12*, 219, 1922.

This resulted in the projection of dark ash-clouds (Fig. 26), and here we encounter an example of our imperfect terminology when, following a simple tumble of dark debris from the broken conelet upon the lava-bath—which continues its emission of gas quite unchanged—the explosions are termed "Vulcanian." At most, they are of the *mixed* type, "tipo misto," and Mercalli himself, author of that terminology, admitted to the writer that no "Vulcanian" explosions, in the sense intended by him, were produced during the liquid-lava phase.

As a rule, during this eruption, the explosive issue of gas from the magma was so nearly continuous that the word *emission* conveys a truer idea (Figs. 29 and 32) of the process than *explosion*. Masses weighing tons were often carried up without apparent convulsive effort.

This factor of continuity attained its extreme manifestation in the "intermediate phase" (Fig. 31), but there were times, both before and after this, when explosions were clearly separated and very sharply defined. Such was the case after noon of April 7, when the "flashing arcs" (p. 40) were produced. This beautiful and interesting phenomenon—here observed, so far as the writer knows, for the first time—has also been observed through ultra-rapid photography of cannon-firing,[1] and was apparently noted under varying conditions during bombardments in the Great War.[2] The causal explosions—with a frequency of from one in three seconds to as many as three per second—were of peculiar sharpness, and clearly indicated the going into action of magma then in a very different physical condition from that which had preceded it. We find ourselves here in a field of pure speculation, but we may surely venture to postulate a material whose position in depth had been such as to confer a degree of viscosity and gas-content that upon liberation would manifest itself in precisely this manner.

Such a supposition is further strengthened by the time at which the phenomenon occurred. This was when the eruptive process was just entering upon the culminating dynamic manifestation, in which there should figure the agency of this deeper and more powerful accumulation. If it be objected that, a little later during that night of the culmination, the magma assumed the same "liquid" qualities which had characterized it during the earlier phenomena, it is but natural that this also, in gradually expanding and discharging its content of gas, should, like the others, undergo that transformation to a greater fluidity which is the normal consequence of a release of overlying pressure and ascent in the conduit.

Another point must here be made clear. The pillar of fire and cloud was often seen to be composed of multiple jets, and, from this fact, a number of explosive "bocche," or mouths, have most inexactly been reported in action.[3] During

[1] Notably by Capt. Francis J. Behr, Coast Artillery School, Fortress Monroe.

[2] *Bulletin Société Astronomique de France*, October 1917, April 1918, June 1919, and others.

[3] Mercalli (Mem. Accad. Lincei, *24*, 9, 1906) attributes the great thickness of the column of "smoke" to the existence of two mouths below, this being inferred from the fact that sometimes "two perfectly contemporaneous incandescent jets were seen." In June 1914 two separate and generally non-synchronous columns of "smoke" were issuing from the large orifice at the bottom of the funnel in the crater-floor. (Day and Washington, Bull. Geol. Soc. Amer., *26*, 379, 1915.) There seems to have been but one column in 1913, shortly after the formation of the funnel. (Malladra, Bol. R. Soc. Geogr., 1914, 753). (H. S. W.)

the night of the culmination and soon after 10 p. m. the final uprise of incandescent magma caused, for a time, a purely "Strombolian" phase with lofty fiery jets plainly seen to be multiple and frequently simultaneous. But these ejections took place from the surface of a column of liquid hundreds of meters in depth, and it is clear that no permanent, solid conformation in the way of a vent fixed in position could have existed there. The phenomenon is due to the fact that the upstreaming of great explosive gas-bubbles and bubble-swarms through the liquid formed paths of lesser resistance, which continued to be followed, producing, for the time, a system of convection along these lines.

This does not mean, however, that the feeding fissure below is incapable of influencing the upper conditions as regards orientation of emission centers. On the contrary, long observational experience has shown the writer that fundamental characteristics are often protracted upward to an extent which is sometimes almost incredible, and to him it is no cause for wonder that he must here testify to the explosive jets of this eruption being generally aligned roughly north to south in correspondence with the postulated subterminal fissure, whose existence can scarcely be doubted.

As described in the "Narrative," this final "lava" uprising culminated after midnight with inclined projections toward the north and east, and then, on the morning of April 8, gave place to the paroxysmal gas-emission of the "intermediate phase." The first of these phenomena has been fully discussed (p. 63), and inasmuch as its explosive features involved no element of novelty, it need not here be reconsidered, but the mechanism of the great gas-phase affects profoundly our conceptions of volcanic manifestation and must now be briefly examined.

This phase of transition was extremely significant, and the writer must insist upon its specific characteristics being recognized in their revelation (1) of an enormous accumulation of gas and concentration in a certain zone; (2) of a magma physically different from the "lava" which had before occupied the upper conduit; (3) of *water* as the main constituent of its volatile content. The first of these postulates is attested by the truly paroxysmal release of energy during the hours of daylight on April 8, 1906, and its subsequent diminution. It has been said[1] that the eruption ended by obstruction, but this was subsequent to, consequent upon, and rendered possible by the beginnings of exhaustion. The significance of the fact of exhaustion lies in this, that as the depth of this material would be such as to have left it longest in contact with water-bearing strata, we may infer that a gradual acquisition of water and rapid discharge of the accumulation constitute the principal features of the process which forms the basis of periodicity.

Peculiarity in the structure of this magma was revealed by its inability to expand rapidly, rise, and be ejected in liquid, incandescent form, but, instead, to be consumed, so to speak, by the paroxysmal evolution of gas from its pores—the "explosion level" eating its way downward during the greater portion of the phase, as described in the section on "Mechanism."

[1] G. Mercalli (3), p. 16.

The presence of water was shown by the aspect of the condensation at the head of the crater-cloud (p. 45) and by the pisolitic and mud precipitations of the following day (p. 48). Its connection with the peculiar physical state of this magma can scarcely be doubted. While far from advocating a return to the earlier extreme conception (Stoppani, etc.) of an aqueo-crystalline magmatic solution which would become *fused* upon the loss of its water when emitted from the volcano, we may, on the basis of these and other considerations already reviewed, conclude in favor of a condition in depth which may be described as a virtually rigid, i. e., very slowly deformable, compressed material, not impervious to gas-transfusion, and changing, during its gradual ascent, into the liquid, vesiculated, subcrateral and crateral lava. The postulated acquisition of water by the magma during its long-continued contact with aqueous strata is denied by many, but the writer can only record his present conviction.

The explosiveness of this phase was manifested by as continuous an emission of vapor under enormous tension as can be imagined, and this has been compared by the writer (p. 46) to the "blowing-off" of a steam-boiler after the water has been ejected. It is impossible to exaggerate the importance of appreciating this element of continuity in the explosive emission if a clear idea is to be had of the dynamics of the eruption, of its sound phenomena (p. 46), and of the conformation imposed upon the volcanic "gun" by the issue of gas. The continuous column of vapor in and through which the escaping masses of gas followed each other in constant succession and with incredible velocity has already been described (p. 45), and a moment's reflection will show how fundamentally different would be the dynamic effect of isolated explosions driven from the muzzle of the bore against a stationary and inert cushion of air. There would result a lateral "blast," with destructive effects upon the crater, reduced altitude of projection, and a seismic reaction, whereas the culmination of this actually preceded instead of followed this maximum of gaseous emission.

The superlative *intensity* of the emission has been described in the "Narrative" and in the section on "Mechanism," and if it were possible to calculate with any degree of accuracy the volume of gas emitted during this phase alone the figures would truly stagger the imagination. It was the revelation of this preponderance of the gaseous element over the solid matter emitted therewith that so deeply impressed upon the writer the conviction that gas is the principal eruptive element and that all else is accessory. In his opinion, failure to realize this basic truth has been the cause of many errors in the conception of volcanic phenomena.

During the night of April 8–9, as has been said, there was effected a complete change from this most powerful evolution of gas, with comparatively insignificant accompaniment of comminuted solid matter, to the low-pressure, ash-laden emission of the third and final period of the eruption (frontispiece and Fig. 32). No contrast could have been greater, and these three phases—that of brightly luminous, effusively and explosively emitted lava intermingled with the black detritus of cone-

disruption, the mighty uprush in the towering pillar of paroxysmally expanding vapor, and the copious outpourings of the dense, dark clouds of ash—were as distinct and as specifically characterized as if each constituted a separate eruption or the normal manifestation of a different volcano.

The dark ash phase commenced as the exhaustion of accumulated energy began to be manifest in the waning power of the blast of gas, which permitted the fall of solid material into the abyss. With this choking of the channel, fairly powerful explosions again occurred, accompanied by trituration and the expulsion of ash and blocks, and with correlated seismic effects which, in their turn, dislodged more material. But even here the time interval between outbursts was so brief that throughout the entire eruption there was not a moment's interruption in the upstreaming cloud (Figs. 24 to 40). To entitle any photograph of this event as "an explosion" is, therefore, misleading, if not incorrect.

There ensued, thus, by this common form of explosive emission, a long-continued contest between the virtually unlimited materials of obstruction and the now declining and but slowly recuperable forces of eruption, with the production of spectacular ash "pine-tree" clouds and days of darkness, with fascinating phenomena and dismal sepulture, until the inevitable final suffocation of the active lava column supervened and explosive phenomena were at an end.

THE SEISMIC EFFECTS.

The absence of any seismograms of the great eruption prevents complete study of the many interesting and important seismic effects, and we must limit our considerations to the physical examination of the two salient phenomena—the continuous macroseismic manifestation during the night of the culmination and the strong, individualized shocks that occurred at 12^h37^m and 2^h30^m a. m. on April 8 (pp. 41, 42). The rhythmic pulsation at this time was a virtual equivalent of the "humming" of a boiler under high pressure. The volcano was a vibrating shell, actually strained and swelled (as revealed in the lifting of its shore-line)[1] by the paroxysmal expansion of an internal and underlying gas-charged magma released with comparative suddenness. And the amplitude of the vibrations was in proportion to the magnitude of the container. By bracing one's back against a stone wall one could determine roughly the complete, back-and-forth vibration, lasting a full second, more rather than less, and this was confirmed by the behavior of the simple pendulums within the Observatory. These had lengths of 42, 92, 192, and 392 centimeters, and, whereas the three longer ones were agitated in irregular spasmodic fashion, the one 42 centimeters long swung back and forth in evident approach to synchronism with the rate of vibration of its support. Moreover, its bob at times actually struck against the wall, involving a total swing of 25 centimeters. It is obvious that a lateral movement of such amplitude in a pendulum of this length could result only from resonance effects of the actuating impulses, which must, therefore, have had a rate slightly in advance of the pendulum's

[1] Cf. Mercalli (3), p. 30.

intrinsic vibration period. Inasmuch as this is 0.6 second, we may assume, for this specific pulse-note of the volcano, a periodicity of between 0.5 and 0.6 second. This may possibly be a multiple or harmonic of some greater and more fundamental interval, or perhaps the synchronous interference of two different and far more rapid vibrations. The lack of a "steady-point"—i. e., a real seismograph—assuming as possible one which could function as such during these conditions, leaves the apparent amplitude of movement of an earth particle one of personal impression, which is apt to err on the side of exaggeration. The amplitude *seemed* to be as much as 10 millimeters, and some idea of the conditions may be had from the fact that during the night of the seismic maximum it was exceedingly difficult to stand quite still—i. e., without shifting one's feet to restore the disturbed center of gravity—and at times the crossing of a room was conveniently accomplished only by making a circuit with a hand against the wall. Experiments recently conducted upon the identical 42-centimeter pendulum show that alternate displacements of its support with a 0.5-second interval of application must reach 2 millimeters in order to produce, cumulatively, such an amplitude of swing as to cause the bob to strike the wall.

The writer's nearly continuous observation of the seismoscopes during the eruption revealed an interesting phenomenon regarding the direction of the volcano's seismic throw. An explosion from the crater produced, as was to be expected, a radial ground impulse—i. e., a west-northwest thrust at the Observatory—but this was invariably followed by movement at right angles, viz., nearly northeast to southwest; and the main rocking of the mountain during the culmination was, as well as could be determined, more nearly in this than in any other direction. It would seem, therefore, that we have here another indirect indication of a persistent subsurface tendency at Vesuvius to southwest migration, with consequent southwest reaction to explosive upthrust against the wall of an inclined vent.

The Observatory building faces due south and its line of weakness runs east and west through the main hall, which communicates with rooms at each end through arched doorways occupying most of the walls in height, and this plane of weakness extends to the second floor, where one room occupies the entire length of the building. The site is almost due west from the volcanic axis (Plate 1) and possibly the orientation of the building (aside from the advantage of a southern exposure) was based upon the principle of having its longer axis on the volcanic radius. If, however, our determination of "seismic throw" is correct, the construction of the building and its emplacement are faulty, for, as it stands, a general north-south movement rocks the structure in the line of its least resistance. At the end of the eruption the walls were badly cracked above the arched doors of the main hall, while a visible crack on the main floor extended the entire east-west length of the building; nor have the repairs, since instituted, wholly prevented a further settling along these lines, which were again plainly visible in 1921. Although it may not be conclusive, there is evidence also of a tendency at this place toward a northeast-southwest seismic movement and eruptive habit, in a partial collapse of the northeast angle of the basement area.

Palmieri[1] speaks of the Observatory as "oscillating continually" during the culmination of the eruption of 1872, and states that "the oscillations were chiefly from northeast to southwest." This tendency (during paroxysmal conditions) may thus be considered as established.

There has existed a fundamental diversity of opinion as to the cause of the two strong earth-shocks which occurred, respectively, at $12^h\ 37^m$ a. m. and 2^h30^m a. m. on April 8 (pp. 41, 42). Mercalli[2] believed them to be due to the falling of masses of the mountain-top into the abyss left by the lava drainage. To this opinion the present writer can not subscribe. The principal disintegration of the edifice took place after these earth-shocks, which were perhaps a cause but not a result. Furthermore, no concussion, however powerful, at the upper part of the Vesuvian edifice could produce such effects as these, which were strongly felt at Naples as true subterranean earthquakes.

Mercalli in another place[3] says that subsequent internal downfalls, although strongly felt upon the flanks of the cone as earth-shakings, were, in general, not even noticed in the Vesuvian towns, and he adds:

"It is natural that these earthquakes of superficial origin should have a very restricted area of perceptibility; inasmuch as we know that the extension of a seismic area is proportional to the depth of the focus of shock."

Nor, in view of what we have seen of the dynamic power of the rising blast of gas (p. 43), then approaching its maximum development, can we admit the possibility of masses of material falling through this mighty uprush of gas and, by concussion against the crater-bottom, producing an earthquake that was felt for miles around.

De Luise[4] writes:

"Two formidable explosions, occurring with a brief interval, announced the avalanching and collapse of the terminal eruptive cone which crowned the summit of the mountain."

The cause was necessarily more profound, and the writer feels certain that it emanated from the region below the volcano, where the feeding-channels would perforce be subjected to a sharp alteration of conditions by the rapid relief of former pressures and the consequent expansion and uprise of their contents—a dislocation and readjustment of strata holding the fissure or magmatic pocket which constituted the immediate feeder of the system. The nature of these shocks was such as would be indicated by this location—a simple back-and-forth movement, which, in the neighborhood of the Observatory, was so much more nearly vertical than horizontal that the lurch of a wooden chalet (p. 42) gave no clear indication of direction.

The important point as to whether the first movement was toward or away from the volcanic axis—i. e., whether the cause consisted of a collapse or upthrust of the strata—can not, we fear, be satisfactorily answered. One may imagine loss

[1] L. Palmieri, *The eruption of Vesuvius in 1872*, p. 96, London, 1873.
[2] G. Mercalli (3), p. 11.
[3] Natura ed Arte, Dec. 1, 1903: *Il Vesuvio dopo l'eruzione del 1906.*
[4] L. de Luise, (1).

of material through upward supply to have so emptied the container as to permit of a settling down, or we may picture such an expansion of the gas-charged magma in the pocket, through the voiding of the overstanding conduit, as to raise the overlying strata in a sudden yielding, of which the bradyseismic lifting of the shore-line[1] would be but a slower and more constant expression. It is, indeed, the fact of this, and the conception of an underlying magma which has precisely the qualities corresponding to such behavior, that inclines the writer towards the second of these hypotheses.

Whatever may have been the initial direction, we have in this form of earth-shock, if our hypothesis of its origin is correct, a specific type—one which, although causally volcanic, has the characteristics of a less fully localized manifestation. It is a type almost to be expected during the culminating phase of an eruption which is truly catastrophic, and it is therefore most interesting to find that one of similar characteristics occurred during the paroxysmal phase of the great eruption of Sakurashima in 1914.[2] In this case there was no collapse of the cone, and no doubt of a subterranean origin has ever been entertained. Professor Schwarz stated to the writer (who arrived later) that the shock moved a small bridge back and forth once only, corresponding with what is normally the motion imparted to a ground particle by simple yielding of strata. At the city of Kagoshima (somewhat nearer to the volcano than is Naples to Vesuvius) the motion was largely vertical and considerable damage was done. The writer believes that many seismic effects recorded during eruptions in the past may be attributed to this specific cause.

THE SOLID EJECTAMENTA.

The solid ejectamenta varied in dimensions from blocks of several cubic meters (p. 89) to impalpable powder. The sources of the materials were no less diversified, these including fresh lava blown directly from the liquid bath, chaotic masses of old cone material, metamorphic blocks from the ancient Monte Somma foundation, and fragments torn from the underlying limestone (p. 13), whose strata were fissured in the original formation of the volcano-vent.[3]

The first material to be ejected consisted of direct projections from the liquid contents of the crater—i. e., lapilli, scoriæ, bombs, and vitreous sand—commingled with debris of the recently formed and now collapsing terminal conelet. All of this, except the air-borne sand, was buried under the later products of explosion and scarcely counts among the eruption's ejectamenta.

With the successive descents of the "explosion-level" (p. 68) and the rapidly increasing force of emission, detritus from the disrupting main cone was thrown out in great quantity and in all states of subdivision, including a large number of blocks up to several tons in weight (Figs. 50 and 51). Many of these yielded fine mineral specimens and—still more important in their revelation of prolonged internal gas permeation—deposits of sublimed salts. Even as late as the autumn

[1] During the culmination, a powerful bradyseismic movement, transient in character, lifted the base of the mountain to an extent which, at Portici, reached 30 centimeters. Cf. Mercalli (3), p. 30.

[2] F. A. Perret, *Sakurashima*. Zeitschr. Vulk., *1*, 139, 1914.

[3] Cf. Lacroix (4) and (5); Zambonini (1).

of 1921 each excursion to the Atrio yielded blocks whose internal cavities are lined with breislakite, wollastonite, anorthite, amphibole, etc., and the sum total of this older matter attests the greater amplitude of the excavating and dredging operations of this eruption as compared with that of 1872.

More unusual, and most interesting for the evidence of enlargement or migration of the conduit and the sinking of the "explosion level" to very considerable depths, were the exotic blocks of limestone,[1] calcined and superficially roasted to varying depths (Fig. 52). Malladra[2] has described, also, two calcareous specimens, one containing fossil shells, which show little or none of that alteration to be expected from long exposure to heat.[3]

50 51

Fig. 50.—An ejected block of old lava with gas bore-holes.
Fig. 51.—Bomb formed of old rock covered by fresh lava.

The ejected material of the northeast inclined jet has been elsewhere described and we must here, as in the other sections, confine our main investigation to the ash. This has most need of elucidation and is more specifically related to the problems of our physical study of the eruption, and this need comes not from any lack of commentators or of comment, but because of a wide disagreement in regard to its origin and mode of production. Substantial unanimity prevails regarding the first product—a coarse, dark sand representing principally the more or less completely subdivided materials of the disrupting terminal conelet, together with vitreous particles from the effervescing lava column—in other words, an atomization of new and recently consolidated material.

[1] Cf. Mierisch, B., *Auswurfsblöcke des Monte Somma;* Tsch. Min. Petr. Mitth., *8*, p. 113, 1887; Johnston-Lavis, *The ejected blocks of Monte Somma;* Part I, stratified limestones; Trans. Edinburgh Geol. Soc., *6*, 314, 1893; Johnston-Lavis, *Eozoonal structure of the ejected blocks of Monte Somma;* Sci. Trans. Dublin Soc., *5*, p. 259, 1894. (H. S. W.)

[2] Malladra (9).

[3] Having maintained, in a previous note, that the lava column had not descended much below the level of the lateral vents (about 600 meters), Malladra finds some difficulty in explaining the contemporary detachment of these specimens which their unaltered condition demands, but the present writer ventures to point out the possibility of a *temporary* descent of the explosion-level to greater depth, as already set forth.

But from this point on opinions diverge. The "intermediate phase" never having been recognized, its ash (although it is a most interesting and instructive product) has not been specifically distinguished, but that of the third period has produced a singular disagreement as to the origin of the material, its mode of formation, and (incredible as it may seem) its physical structure and composition. Mercalli[1] insisted that all the ash emitted subsequently to the luminous period (first phase) resulted from the trituration of old cone material, denying any contemporaneous magmatic contribution and refusing to concede that the matter was open to discussion. He agreed with the writer as to the general inadequacy of chemical analysis as a means of determining the origin of a sample, inasmuch as most of the material has virtually the same composition, but he considered such factors as non-luminosity, oxidation as shown by reddish tint, progressive fineness of subdivision, etc., as conclusive and final arguments.

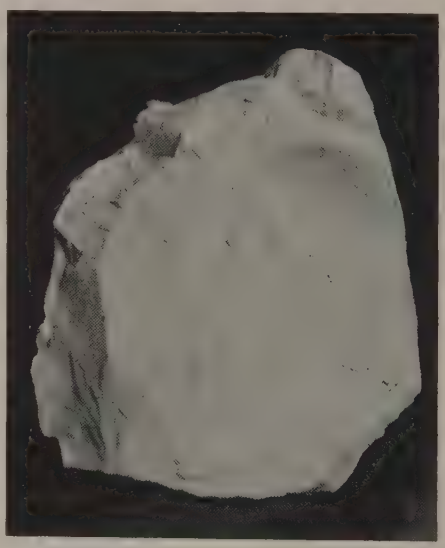


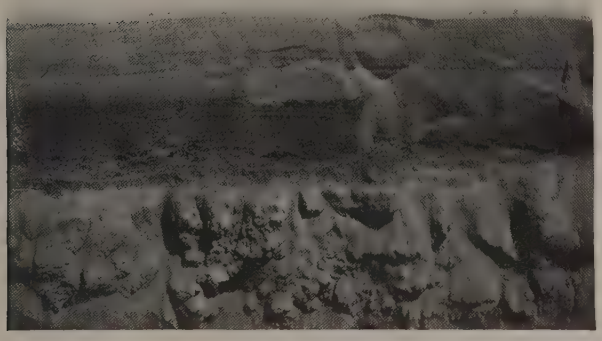
Fig. 52.—Block of limestone ejected during the eruption.

The present writer believes this extreme view to be untenable by anyone who, from the standpoint of the physicist, views with clearness the mechanism of the eruption, and this positiveness of Mercalli seems stranger from the fact that many of his compatriots had already demonstrated convincingly the frequent direct participation of magma in the production of ash. Borelli,[2] in his *Meteorologia dell' Etna*, speaks of ash being formed "by the congelation of fluid material which, spurting into the air, may suddenly cool in minute particles of sand, and . . . may then suffer the same atomization as other pumice or stones." Scacchi devoted a masterly paper to the subject in 1886.[3] Toniolo,[4] writing of the effects of this Vesuvian eruption upon the volcanic cone, concludes: "We must therefore admit that the crater of Vesuvius descended to greater depths, or else that a great part of the material expelled from the central crater was in the form of fluid lava pulverized by the explosions." And although this refers to upper lava in contact with the atmosphere (as was not the case during the third period of the 1906 eruption), Johnston-Lavis[5] most clearly describes the change of the deeper conduit magma into gas and ash. Dana,[6] writing of the "thread-lace scoria" of Kilauea, suggested that a further subdivision

[1] G. Mercalli, *La grande eruzione vesuviana*, Mem. Accad. Lincei, 1906.
[2] Borelli, J. A., *Historia et meteorologia incendii Aetnaei anno 1669;* Regio Julio, 1670.
[3] Scacchi, A., *Le eruzioni polverose e filamentose dei vulcani;* Atti Accad. Sci. fis. mat. Napoli (2), *2*, 1886.
[4] Toniolo, A. R., *Studio orometrico sulle variazioni del cono vesuviano dopo l'eruzione del 1906;* Riv. Fis. Mat. Sci. Nat., *7*, No. 77, Pavia, 1906.
[5] Johnston-Lavis, H. J., *The mechanism of volcanic action;* Geol. Mag., Dec. 5, Vol. 6, p. 423, 1909.
[6] Dana, J. D., *Characteristics of volcanoes*, p. 166, New York, 1890.

of the material might produce ash, and claimed that such a process would be an explanation of ash formation more reasonable than the trituration of rocks.[1]

The present writer in 1912 (not knowing that he had been anticipated) published a paper[2] setting forth the hypothesis of the direct conversion of the material in the lower conduit into magmatic ash upon release of pressure, citing the mechanism of the "Intermediate Phase" of this eruption as a case in point. Other students of the Vesuvius eruption of 1906 have published observations which imply contemporary origin. Thus, Brunhuber[3] says of all of the material other than the first ejection, which was of sand: "The material of the later samples consists principally of finely divided glass." Prinz[4] says of the contemporaneous scoriæ thrown over Ottajano, that "grinding transforms these to a gray powder having all the characteristics of the later ash."



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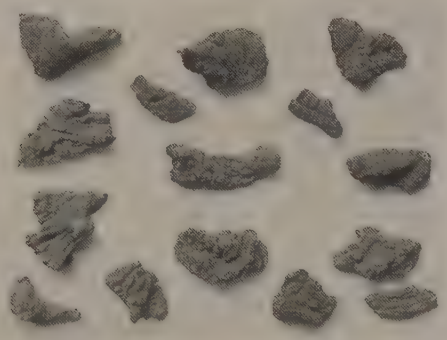

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Fig. 53.—Section of ash strata at Observatory; depth is 30 centimeters.
Fig. 54.—Lapilli (natural size) ejected April 4–5.

But the truth lies, as usual, between the two extremes, or, rather, in the participation of both. In fact, there is, in all the collections of the ash from the various phases of this eruption, no such thing as a perfectly distinct type. This should be evident to all who have studied both the material and the mechanism of the eruption. Examination of a given specimen should therefore take account of the predominating material, with consideration of the observed conditions of emission from the crater.

Sixteen specimens of ash, including one of fine lapilli, gathered from the terraces of the Observatory, soon after falling, between the early morning of April 4 and April 20–21, inclusive (Fig. 53), were examined by the writer.[5] (See Table 1.) They show considerable diversity in size of grain, in color, and apparently in mineral composition, but in the absence of a proper microscopic study nothing

[1] S. von Waltershausen (*Der Etna*, Leipzig, 1880, *2*, p. 468) suggests this origin for the ash of Etna. (H. S. W.)
[2] Perret (3).
[3] Brunhuber, A., *Beobachtungen ueber die Vesuveruption im April 1906;* Beil. Ber., naturw. Ver. Regensburg, *10*, 1906.
[4] Prinz, W., *L'éruption du Vésuve d'Avril 1906;* Ciel et Terre, No. 5–7, Bruxelles, 1906.
[5] Mercalli (3) gives brief descriptions of the ash of different dates; they agree in general with those of Perret. (H. S. W.)

definite can be said as to this last character. Some of them apparently contained a hydrocarbon having a consistency between that of vaseline and paraffine, revealed by leaching with chloroform and subsequent evaporation of the solvent.

All the specimens, except that of lapilli of April 4–5 (Fig. 54), are seen to be (probably) the result of trituration and not unaltered ejecta in drops and filaments from the lava. This, however, does not warrant the deduction that none of this material is contemporaneous with the lava. The fact of trituration merely attests the violent explosiveness, in the early stages, of a great eruption, by which even the smaller solidified droplets, derived directly from the molten lava, may be pulverized by attrition between themselves—a process which would be much intensified in the churning movements of the third phase.

TABLE 1.—*Descriptions of Samples of Ash.*[1]

No. 1; April 4, early morning. Coarse, rough sand; the grains up to 2 millimeters in diameter. Color dark gray, the result of a mixture of nearly black opaque particles with others of a lighter tint and transparent, the two being easily distinguishable with the unaided eye. Many grains are composed of both these elements. The specimen is quite free from soluble salts.

No. 2; April 4, morning. Sand similar to No. 1, but of much finer grain, the average size of the grains being less than half that of No. 1. There is a larger proportion of transparent grains, many of which are yellowish brown. Soluble salts are absent.

No. 3; April 4, afternoon. Sand still finer than No. 2; gray with a very slight reddish tinge. Much larger proportion of rounded opaque grains, which are almost completely covered with salts.

No. 4; April 4–5, night. Small lapilli, averaging 0.5 to 2 centimeters in diameter, mostly elongated and contorted. The color is warm gray; the lapilli are exceedingly light in weight, because of their great vesiculation, and are really vitreous but of earthy appearance. They have apparently been blown directly from the effervescing lava in free contact with the atmosphere.

No. 5; April 5, early morning. Sand mixed with the lapilli of No. 4. Coarser than No. 3, with a greater prevalence of opaque grains. The sand is virtually free from salts.

No. 6; Ash much finer than any of the preceding. Color is warm gray and transparent grains prevail. The ash shows a tendency to agglomeration.

No. 7; April 8.[2] Fine ash, which, freed from its soluble salts by leaching, is seen to be composed almost entirely of white or yellowish, transparent grains, the larger of these being generally rounded.

No. 8; April 8–9, night. Fine ash, between gray and brown, containing pisolites up to 1 millimeter in diameter. It is more earthy in texture than the preceding.

No. 9; April 9, morning. Ash very similar to No. 8, but entirely agglomerated into pisolites of all degrees of fineness up to 3.5 millimeters in diameter.

No. 10; April 9, afternoon. Ash prevalently of fine light, translucent grains, but with some larger opaque grains, making the mixture exceedingly gritty. The color is colder than Nos. 8 and 9. There are a few pisolites.

No. 11; April 12. Ash pinker and much finer than any of the preceding and with an abundance of very minute pisolites.

No. 12; April 12–13, night. Ash very much like No. 11, but lighter in color and containing what is thought to be microsommite, although this was not positively identified by appropriate tests.

No. 13; April 13–14, night. Ash still lighter in color. There are present micropisolites caused by the agglomeration of fine ash about minute, hard, usually opaque nuclei.

No. 14; April 15–16, afternoon. Very fine ash, the grains being uniform in size and of a light-gray color. Much soluble salt is present, to which the light color is due in part, but not entirely, as many white ash grains are present.

No. 15; April 16, afternoon. Ash of same color as No. 14, less smooth to the touch, and containing peculiar white filaments the nature and origin of which are unknown. Most of the larger grains of the ash are white and more spherical than the smaller.

No. 16; April 20–21. Extremely fine, impalpable ash, that floats in the air. The color is very light gray, verging on violet. It is composed of very minute white and translucent grains, with some salts.

[1] It is greatly to be regretted that, apparently, no microscopical examination was made of these samples of ash, to determine the mineral composition, nor chemical examination of the "salts". (H. S. W.)

[2] This specimen was given by Mr. T. W. Allen, of Naples.

As regards further arguments against the possibility of contemporaneous magmatic contribution to the ash, that of non-luminosity may be rebutted on the ground of the great depth of the explosion-level in the "Intermediate Phase," together with extreme subdivision and relative scarcity of ash. Darkness also dominated during the third phase. The criticism that the red tint of the ash indicates an already oxidized condition falls to the ground before the fact—apparently not generally known—that the material, when ejected, was gray, and that it assumed the reddish tint some hours later, through a process of oxidation, to which, seemingly, the water vapor in the emanation contributed.

We feel justified in concluding—on the basis of our study of the mechanism of the eruption and the considerations in this section—that a large proportion of the ash was derived directly from the magmatic column through paroxysmal expansion of its contained gas, the remainder being edifice material, and the whole having been subjected to continuous trituration and progressive dissipation of the less-resisting elements until there remained but the exceedingly comminuted, hard particles.

[Perret gives no calculation of the total amount of solid material ejected during the eruption. Sabatini (3), p. 1110, estimates the volume of the total amount of ash as at least 211,000,000 cubic meters. Its distribution (largely determined by the wind) over the area and its depth at various places are described by Mercalli (1) and De Fiore (1), page 14. The ash is said to have been carried to Paris and Neustadt (Schleswig-Holstein), Dalmatia, Montenegro, and Sicily. It was thickest in the northeast sector, reaching a maximum of 125 centimeters near Ottajano, but generally about 80 here. At the Observatory it was about 30 centimeters (Perret), about 25 at the Hotel Eremo, 10 at Resina, 2.5 at Naples, 2 at Capri, 0.5 at Pozzuoli, and 0.4 at Ischia. In the sector about Pompeii, Boscotrecase, and Torre Annunziata it seems to have been but a few millimeters thick. H. S. W.]

THE HOT AVALANCHES.

The term "hot avalanche" is not applied here to the momentary down-plunge of igneous fragments that covered the mountain-top during the evening of April 7 (p. 39), but refers to the sliding down of the enormous quantities of detrital material which constantly accumulated upon the cone during the last phase of the eruption. The true mechanism of this phenomenon has been briefly referred to in the "Narrative."

The detritus, forming strata as much as 15 meters deep, rested in unstable equilibrium upon a slope which at a certain distance from the lip of the crater descended at an angle of from 32° to 35°. The mass, although including fragments of all dimensions up to several cubic meters, was composed mainly of fine ash at an elevated temperature, in consequence of which there was maintained such a dilatation of the interstitial gas as to give to the whole the quality of a dry quicksand having a quite extraordinary degree of potential mobility. Thus a shock of any kind would detach masses of this material, which then descended the steep incline, the concussion of transported blocks being muffled and cushioned by the enveloping mass of fine powder.

Although from the Observatory—and even from points nearer to the crater during excursions—it was difficult to perceive the actual beginning of the ava-

lanches, there could be no doubt that these were often started by large ejected blocks and fragments, the falling of which could frequently be heard. But the uniform distribution of the loci around the outer circumference of the crater, as recorded in the sculpture of the cone (Fig. 44), clearly shows the principal cause to have been a simple shaking down, all around the cone, of the materials which uniformly ringed the top of the mountain, either through seismic tremors or even mere gravitational yielding to overaccumulation. The conditions portrayed in Plate 8 will reveal how incessant must have been the rain of ash upon the slopes of the cone. This extraordinary regularity of distribution (Plate 10) and the remarkable uniformity in the dimensions of these furrows, as well as their depth and clear-cut section—both valleys and ridges—could result only from a long-continued supply of material with oft-repeated slips.

The hot avalanche resembles a snow avalanche, except that the materials of which the hot avalanche is composed permit this to move more rapidly and farther on a given slope, whereas the material of the snow avalanche ultimately packs and consolidates the mass, thus arresting its motion.[1]

The nuée ardente differs fundamentally from the simple hot avalanche in that it is caused by the upward and outward projection of material that is immediately derived from and still retains some of the characters of the active, gas-emitting magma, especially its very high temperature. The nuée ardente is thus directly connected with, or forms a part of, the explosive activity.

The material of the hot avalanches of the Vesuvian eruption of 1906, on the other hand, although composed largely of fresh ash, was not connected directly with the explosive activity. The greater part of the very fine-grained avalanche material accumulated during the third great ash-phase, and although it was still hot it had come to rest on the outer slopes of the cone. Its motion, therefore, was simply gravitational and not due to explosive propulsion. Although Lacroix[2] was inclined to believe that, with a slightly greater density, some of these Vesuvian masses of ash might have formed true nuées ardentes, and although the fall of cold débris in the interior of the crater may produce a well-defined "cauliflower" ash-cloud, the writer insists on a clear distinction between the phenomena.

In the opinion of Lacroix, the true nuée ardente is an avalanche of live magma, which is extremely mobile, not only because it is composed of very hot gases, bearing fragmental and comminuted material, but because the solid particles themselves are emitting gas which tends to keep up the motion originally imparted to them on expulsion (Fig. 55).

The simple hot avalanche is of the same order of phenomena as the mud-flow and the internal slides of the "repose period," from which it differs essentially only in the mobility imparted to it by the elevated temperature of the gas between the particles of ash. The nuée ardente, on the other hand, may be considered as being intermediate between the ash-laden cloud driven upward by the explosion of lava highly charged with gas and a flow of liquid lava that is comparatively free from gas.

[1] Lacroix (Bull. Soc. Géol., France, *6*, 357, 1906) also describes and compares them (the hot avalanches) with snow avalanches and with nuées ardentes. (H. S. W.)

[2] A. Lacroix (1).

Having thus considered the characteristics of the simple hot avalanche and the true nuée ardente, the reader will not be surprised to find the former of these presenting an appearance in strong contrast with that of its powerful rival. Plate 8 shows a hot avalanche descending the cone directly toward the Observatory and just beginning to abut against the intervening lava cupola of 1905 (Colle Umberto I), by which it was deflected, and, passing in front of and below the Observatory, was again photographed as represented in Fig. 35. The transportation of the material by gravity alone is clearly revealed in the lagging of the comparatively tenuous cloud of dust behind the advancing mass of the avalanche.

Although the lack of any power of self-movement in the materials must be insisted upon as a characteristic of the phenomenon, yet the elevated temperature of the mass must not be overlooked. The fallen material filled all hollows with a dry quicksand so dilated that even small stones sank quickly out of sight, and the temperature—which before transportation from the regions surrounding the crater may have attained 700° or 800°—although greatly reduced in transit, was further lowered very slowly because of the insulation afforded by the immobile interstitial air. Even a bucketful of the fine, hot ash was too hot to touch at the end of 24 hours.[1]

The sculpture of the cone (Fig. 44) gives evidence of the number of avalanches which were produced during the third period of the eruption, especially when it is remembered that each groove was the carrier of many slides. The phenomenon formed one of the many perils attending excursions upon the volcano during this time, both on account of the insidious filling of the hollows underfoot and the direct danger of one of these swift, scorching masses coming in our direction.

On losing its heat the finely divided material gradually subsided to a compact condition, so that it readily supported a person, having lost with its heat the peculiar qualities which gave it its power of extreme mobility. Reaccumulation of the material of the fallen avalanches formed many imposing masses of breccia and greatly altered the shape of the cone, a work which was completed later by the mud-flows of the "repose period." The "hot avalanche" must be considered as one of the remarkable features of the eruption, if only as an unusual example of extremely rapid erosion.

The writer does not contend that a true nuée ardente has not been, or could not be, formed at Vesuvius; but he thinks that none was, or could have been, formed during the eruption of 1906. For the formation of a nuée ardente there must be present a very pasty lava, very highly charged with gas, and so near the mouth of the crater that it might be expelled in the form shown at Mont Pelée. At Vesuvius, however, during the eruption of 1906, the conduit was continuously open, so that excess gas could readily escape from the lava near the mouth of the crater, and the lava was thus maintained in a state of comparative quiet and with a low content of gas. When this upper quiet part of the column of lava had escaped through lateral fissures, the deeper portion of the column (below the level of explosion) was exposed. This lower lava, being surcharged with gas, was

[1] De Fiore (1), p. 20, states that this ash "preserved its heat for a long time." Experience, in the Geophysical Laboratory, with extremely fine magnesia powder is not in accord with this last statement of Perret. (H. S. W.)

violently blown out as ash, along with the escaping gas, to an enormous height, the expulsion constituting the great "intermediate phase."

A "basic" chemical composition, and consequently easy fusibility or high liquidity, do not necessarily preclude explosive activity, and under different conditions, which would have been determined largely by the state of the volcano before the eruption, a Peléean nuée ardente may well have been a feature of past Vesuvian eruptions. There are reasons for believing this to have happened during the Plinian eruption of 79 A. D., and several observations since then point to a

Fig. 55.—A true nuée ardente at Mont Pelée. Note the forward projection of cloud. Height is 4,000 meters. Photograph by Lacroix.

repetition of this form of activity at other eruptions of Vesuvius. The nuée ardente is now thought to be less unusual than was supposed at first. The writer thinks that something of the kind occurred at the eruption of Sakurashima in 1914,[1] and Fenner has recently offered a similar explanation for the hot-ash deposits in the Valley of Ten Thousand Smokes at Katmai.[2]

THE ELECTRICAL PHENOMENA.

When particles are projected from a volcano into the atmosphere they will be electrically charged with respect to the earth. Falling volcanic ash is therefore invariably electrically charged.

The chief cause of the principal manifestations resides in the volcano. The visible and audible electrical effects are produced probably in great part by the

[1] F. A. Perret, *Sakurashima*, Zeitschr. Vulkan., *1*, 137, 1914.

[2] C. N. Fenner, *On the origin and mode of emplacement of the great tuff deposits of the Valley of Ten Thousand Smokes;* Nat. Geogr. Soc. Tech. Papers, Katmai Series, No. 1, p. 24, 1923.

explosive emission of gas and detritus and are seemingly due mainly to friction between gases and solids, although the condensation of water vapor may be a contributing cause. Electrical manifestations are therefore among the principal accessory phenomena at all eruptions having the proper conditions.

The production of electricity during a volcanic eruption may be compared with that from the old Armstrong electrical machine, in which electricity is generated by the friction of dry steam (issuing from a boiler) through wooden nozzles. An apparent difference is that in a volcanic eruption most of the discharges take place within the ash-cloud. The discrepancy may be explained by the facts (1) that the volcanic emission of vapor is not perfectly continuous and (2) that the effective friction in the volcanic cloud is not so much between vapor and vent as between vapor and ash. Observation shows that electrical displays in volcanic eruptions are dependent on the amount of ash. The electrical potential of the cloud may eventually become so great that discharge will take place between it and the earth (p. 50). This is illustrated in Fig. 36.

That this may not always take place is to be inferred from the words of Palmieri[1] regarding the eruption of 1872:

> "Hence it follows that the flashes of lightning of Vesuvius play through the smoke, and with difficulty strike bodies upon the earth; and from this circumstances our ancestors believed the thunderbolts of Vesuvius to be harmless. However, if the smoke be very great, and driven by the force of the wind to some distance from the crater, with an abundant fall of ashes, it would be possible to have lightning-flashes proceed from the smoke to the earth."

The first electric discharges in the crater-cloud (p. 37) were short, straight flashes, producing sharp, staccato, snapping sounds with complete lack of reverberation. With augmented power they increased in length and when formed between horizontal points they were upwardly curved like an artificial electric arc. The trajectory also became sinuous and even apparently forked.

Brunhuber[2] observed "electrical discharges" in the form of "fine points and fine lines," but it is probable that the "points" were straight flashes seen endwise, as throughout the entire eruption no manifestation of "scintillating points" or anything in the nature of "stellar lightning" was observed by us upon the mountain, under the most perfect conditions of seeing. The phenomenon of "globe-lightning" was not observed in the crater-cloud, though at Ottajano balls of fire were said to have struck the ground and to have disappeared without leaving a trace[3] (p. 63).

Our slight knowledge of the mode of action of this peculiar manifestation of electricity forbids the rejection of this observation. The writer, at Stromboli in 1907, observed a magnificent fire-globe emerge horizontally from near the base of the crater-cloud. It was bright blue, and in the ruddy glare of the surroundings it shone steadily for a full minute, then shot out a forked flash, and finally vanished. This globe could not have been less than 1 meter in diameter.

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[1] L. Palmieri, *The eruption of Vesuvius in 1872*, London, 1873, p. 133.

[2] A. Brunhuber, *Beobachtungen über die Vesuveruption, im April 1906;* Beilage zu den Berichten des naturwissenschaftlichen Vereins Regensburg 1906.

[3] Mercalli states that "globes of fire" were seen at Ottajano during the night of April 7–8. *La grande eruzione vesuviana.* Mem. Accad. Lincei, p. 9 of separate, 1906.

During the night of the culmination, discharges were taking place in the crater-cloud, and that there was a general and powerful electrical disturbance was shown by the transmission of electricity from the vicinity of the cone to the locality of the Observatory along the overhead equipment of the Vesuvian railway. Flashes and arcs were formed over insulators and across lightning-arresters, and the wires appeared to be incandescent. But the maximum development of "field" (perceptible at our altitude) occurred during the third period, when, with the occasional lowering of the ash-cloud (p. 50), St. Elmo's fire was everywhere and the difference in potential for each meter of height was very great. The determination of polarity would have been of intense interest, but this could not be done at the time. Had it been sufficiently dark, the writer might have determined this by the appearance of brush or glow from a point, but even under the cloud the phenomenon remained invisible, although strongly audible.

No electrical phenomena have been observed during a purely "Strombolian" phase, even when the ejected liquid is quite finely divided and most abundant. This may be due to the condensation of water vapor being impossible in contact with material at such temperatures, but more probably, in the writer's opinion, to the discharging effect of incandescent materials which would act as does a flame or a point. It was said that discharges produced by induction took place during the eruption in atmospheric clouds, but the effects may have been due to simple reverberation. Electrical effects are said[1] to have been observed over flowing lava, possibly from local eruptive activity.

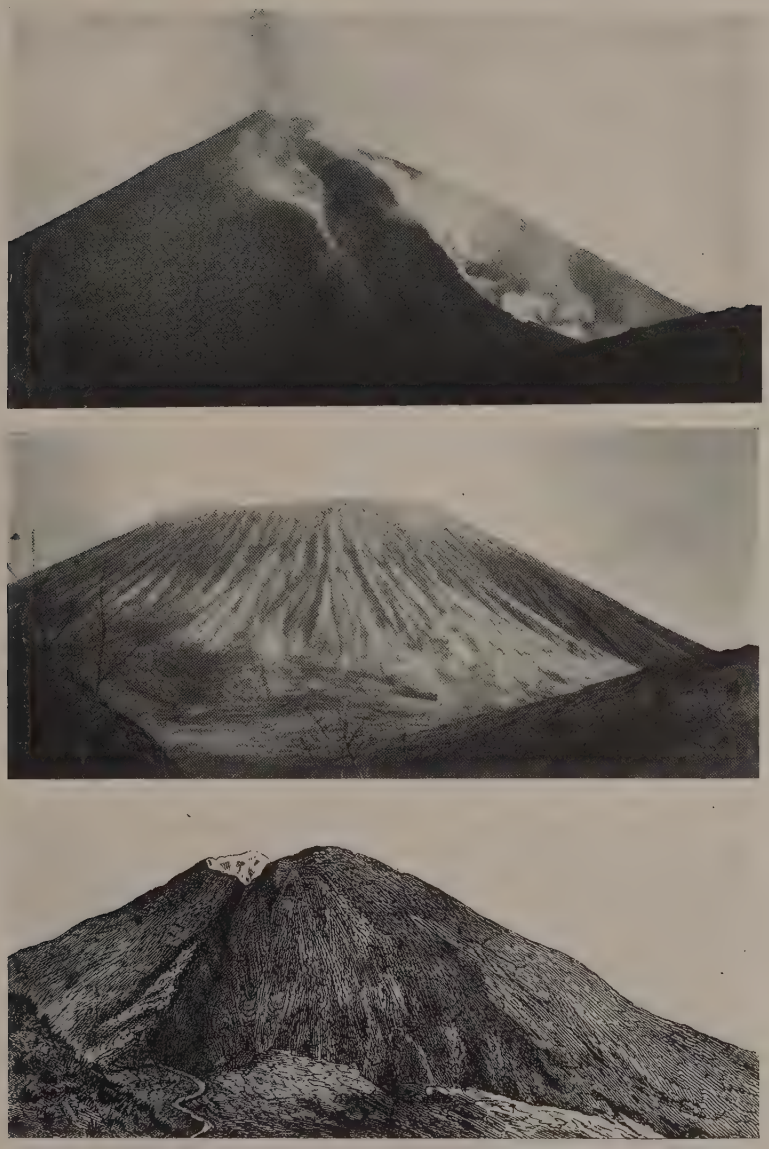
Artificial production of these phenomena, through a modified Armstrong apparatus, is wholly feasible and should be tried; the writer has advocated this since 1907. As it frequently happens that laboratory experiment in support, or otherwise, of some volcanological hypothesis is inconclusive because of the difficulty of reproducing perfectly the subterranean conditions, it would seem especially desirable that an experiment so easily carried out should add its revelations to our little knowledge of these spectacular and often dangerous accessory phenomena of a paroxysmal eruption.

DEGRADATION AND COLLAPSE.

The reduction in height of the mountain as a result of the paroxysmal activity has been described in the "Narrative" (p. 56) and its measurements have been tabulated; its causes are discussed in the chapter on "Mechanism." Briefly restated, these causes were the collapse of the terminal structure, which had been built up by moderate projections of liquid lava around a progressively diminishing aperture, and the ejection of this material by gradually increasing explosions of gas from the deeper magma. As a result, the material of the upper part of the cone was scattered over the surrounding country.

The spectacular change in the aspect of the volcano (Plate 11), caused by the decapitation of the pointed cone familiar to the last generation, quite overshadowed two further examples of external collapse, insignificant in scale as compared with the above-mentioned cone degradation, but no less interesting to the student because of the processes involved.

[1] Anonymous writer on 1737 eruption (p. 250).



Comparative views showing: (upper) the Vesuvian cone immediately before the eruption; (middle) the cone just after the eruption; (lower) the cone after the eruption of 1872, from a drawing by Monticelli. Note the absence, in the lower right-hand corner, of the lava cupola of 1895.

Both of these occurred during, and resulted from, the paroxysmal emission of lava during the culminating uprise and outflow on the night of April 7. There was formed upon the southeastern flank, after the effusion of 12,000,000 cubic meters of lava, constituting the principal fluent ejections of this eruption, a collapsed area, roughly elliptical in shape, whose general outline and position are clearly shown in Fig. 56 and more in detail in Fig. 37. This sunken area included the site of the former Casa Fiorenza, and its horizontal extension constituted, in the writer's opinion, an almost conclusive proof that there had been formed a series of lava-injected fractures on this side of the mountain. Moreover, as pointed out in the chapter on the "Fluent Lava" (p. 74), there is good reason to suppose that the intrusions formed extensive chambers whose subsequent drainage resulted in the superficial collapse.

Fig. 56.—The great southern area of collapse.

As far back as 1737, the anonymous author whose acute observations and quaint language are frequently quoted in this work[1] describes a similar occurrence in these words:

"Above this new crevice (from which had issued the principal lava of that eruption) there was seen to be broken and collapsed a large portion of the mountain, as though a niche had been artificially excavated . . . . and we must believe such a collapse to have occurred through the shaking together and, as it were, absorption by the underlying abyss opened by the force of the fire and then filled with the materials of the mountain itself."

These accurate reflections of nearly two centuries ago apply perfectly to the present case in a phenomenon which is but the natural and common result of any considerable and rapid lateral outflow of lava.

[1] *Istoria dell'Incendio del Vesuvio accaduto nel mese di Maggio dell'Anno MDCCXXXVII.* Scritta per l'Accademia delle Scienze. Napoli, 1738.

At Etna, in 1910, the area of collapse was proportionate to the greatness of the liquid ejection, and at Teneriffe, in 1909,[1] if external subsidence was not evident, this was only because of the extremely small quantity of the emitted fluent material.

The second external collapse also occurred, it is almost certain, during the night of the culmination, April 7–8, and most probably during the period of the final uprise of the magma in the conduit just before midnight, although it was possibly earlier in the day. Like the first, its cause was undoubtedly an outflow of lava through the north-northeast sector of the cone at a considerable altitude, the effusion being so short-lived as to form only a cascade, self-arrested for lack of further material (Fig. 45). It is this fact which suggests the probability that the outflow took place during the magma's brief final ascent and in connection with the disintegration of the mountain-top (p. 41).

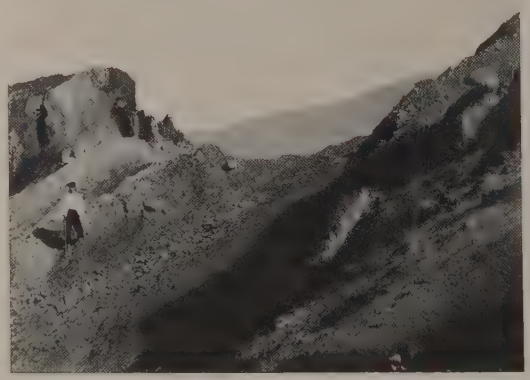


Fig. 57.—The U-shaped cleft of the "échancrure" on the north-northeast rim of crater. Photograph by Mercalli.

At all events, there resulted a depression at this point which constituted, at the close of the eruption, the lowest point on the crater-rim and which has become celebrated, in a small way, partly because of Lacroix's apposite naming of "échancrure" and by reason of a diversity of opinion as to the part it played in the bombardment of Ottajano. As this has been fully discussed in the chapter on "Mechanism" (p. 63), it may suffice to state here that some have believed it an *effect* of the great inclined jet, while others—including Mercalli, who called it a "feritoia" (loop-hole)[2]—would make it no less than the *cause* of that disaster. The present writer (an eye-witness at close range of the phenomena of the eruption) is convinced that the famous "échancrure" had little, if anything, to do with the oblique northeast projections, for reasons given elsewhere (p. 64), and that it was formed by collapse of the crater-rim, undermined by lava-outflow through its fissured walls at a point sufficiently near the summit to have resulted in a vertical subsidence of overstanding material. A photograph of the "échancrure," by Mercalli, reproduced in Fig. 57, clearly shows the phenomenon of true collapse, and this (together with the objective reality of the lava extrusion and the extension of cone-fissures in this direction as far as the base of Somma) leaves, it would seem, no further doubt as to its mode of formation.

[1] F. A. Perret, *The volcanic eruption at Teneriffe in the autumn of 1909.* Zeits. Vulk., *1*, 20, 1914.

[2] Probably in "Vesuvio e la grande erigione del 1906." Ed. Colaveechia, Napoli, 1906. Mercalli calls it a "slabratura" (hare-lip) in Mem. Acc. Lincei, *24*, p. 18, 1906. Malladra also calls it "slabratura," "Nel cratere del Vesuvio." Boll. R. Soc. Geogr., 1914, p. 773. See G. Ponte, Mem. Atti Accad. Sci. fis. mat. Napoli, *15*, No. 14, p. 12, 1913. (H. S. W.)

PART III. REPOSE PERIOD, 1906-1913.

MORPHOLOGY.

In a paper on the characteristics of the phenomena of the "repose period," published in 1909,[1] the writer—after pointing out the definite periodicity in the modern eruptive processes of this volcano, each culminating in a paroxysm followed by an interval of inactivity—used the following words, which may serve as an introduction to the present section:

"It should be noted, however, that if these repose periods mark the end of one era of activity, they also herald the dawn of the next to come. The condition of repose is apparent and external, and represents a preparatory phase which forms a part of the cycle of events. This should not be considered, therefore, as an interval of time during which the volcano is uninteresting, but rather as offering a precious opportunity for investigating the methods by which the hidden forces develop into a condition of external activity, and for studying at close range the chemical and other phenomena which may serve as indices of future eruption. Owing to the exceptional duration of the last eruptive period (1875–1905) and the violence of its culminating paroxysm, the present rest-period may be expected to be of greater than the average length and of more than ordinary interest."

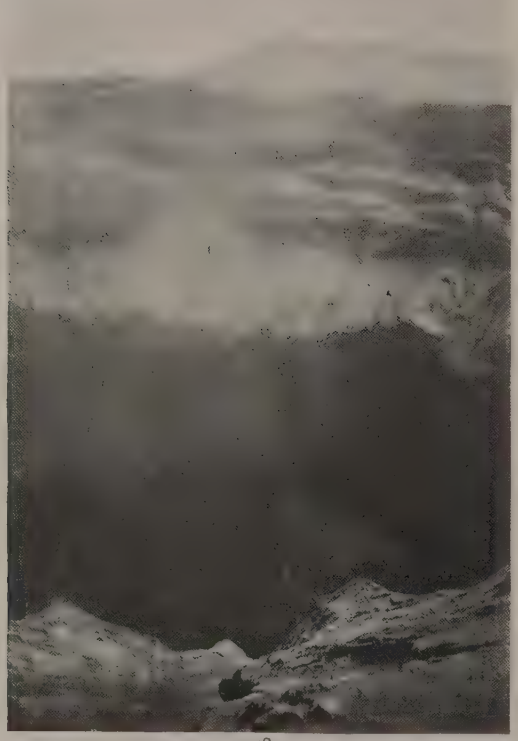
The three years, then elapsed, were extended to seven, and it is to a consideration of the characteristic features of this period that Part III of the present volume is dedicated. But before entering upon a detailed study of its phenomena it will be advisable to devote some attention to the morphology of the mountain, the form of the upper portion of which was profoundly modified by the various dynamic agencies of the great eruption.

Corrected measurements give 107 meters as the minimum lowering of the mountain's height (west-northwest rim), while the maximum, almost diametrically opposite, was 220 meters. The lowest point of the crater's edge, just after the eruption, was the collapsed portion of the north-northeast rim (p. 56). But the internal avalanches (of daily occurrence during the first portion of the repose period) caused rapid changes in the outline of the crater. These were most accentuated in the vertical sense within the eastern wall, where the cone is composed principally of friable materials (Fig. 58). Inasmuch as each meter of reduction in height by this means implied the removal of several meters of material, measured horizontally, it will be obvious that the diameters of the crater were thus still further increased after the close of the eruption.

The inner form of the abyss just after the eruption was that of a wide-throated funnel with a comparatively short flange having an inclination of about 45 degrees. Strictly speaking, there was no longer a crater, in the true sense of the word, the tube extending downward, with no bottom visible from any portion of the summit.

[1] F. A. Perret (1).

The bottom was estimated to be some 600 or 700 meters below the rim (Matteucci). The central well was roughly circular, from 400 to 500 meters in diameter, and its upper edge was sharply defined before the contours were destroyed by internal avalanches (Fig. 58), which clearly reveals the conformation of this tubular channel, cored out by the powerful blast of the great gaseous culmination. Traces of this formation were still perceptible as late as November 1909, especially below the easterly rim, as shown in Fig. 59. By this time the tube had become filled, by the collapsed material, up to a level which brought the bottom into view,



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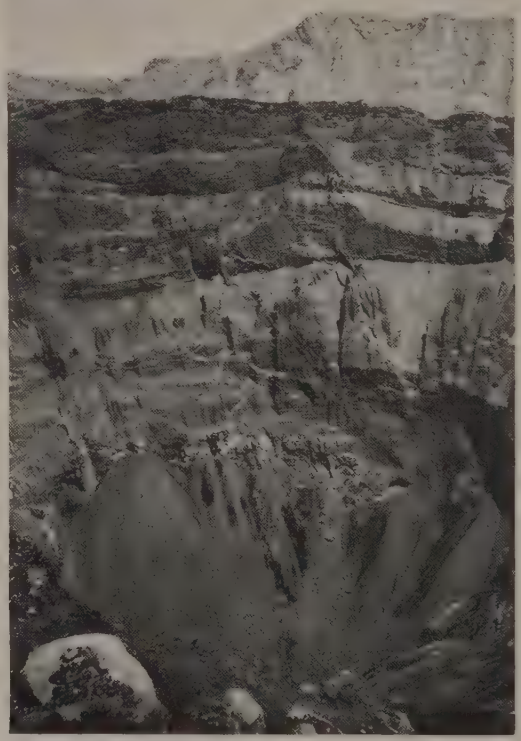

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Fig. 58.—View of crater after the eruption, looking northward and showing the sharply defined upper edge of the central well. The depth of the crater is so great that the bottom is not visible.

Fig. 59.—The same view three years later, showing the crater walls cleaned by erosion and exposing dikes and sills. The bottom is now visible, having risen through filling by the falling of internal avalanches, and talus conoids soften the lower angles.

and a series of talus conoids softened the lower angles, giving again to the great gulf its normal crater form. A general view of the crater, comprising an angle of nearly 180 degrees, looking southward and including the east and south walls, is shown in the composite photograph reproduced in Plate 12.

[The changes in plan of the crater-rim before and immediately after the eruption of 1906, and in 1913, are shown in Fig. 69, taken from Malladra (cf. p. 113). De Fiore[1] also gives comparative maps of the crater before and after the eruption. (H. S. W).]

[1]O. de Fiore (1), plate I.

Panoramic view of interior of crater from the north in 1909. The view embraces 180°.

Besides the decapitation of the cone and the enlargement of its crater, the form of the mountain was altered by the deposition of material transported through the agency of hot avalanches and mud-flows, these accumulations widening the cone at its base and helping to fill the ever-decreasing gap of the Atrio del Cavallo to an extent which can be appreciated by an inspection of the comparative views in Plate 13.

INTERNAL AVALANCHES.

The first of these intra-crateral downfalls took place during the final manifestations of eruption and were frequently mistaken for a revival of true activity. The nearly vertical inner walls of the crater did not form an angle of repose, although their incoherent materials were braced and supported by a network of dikes; at

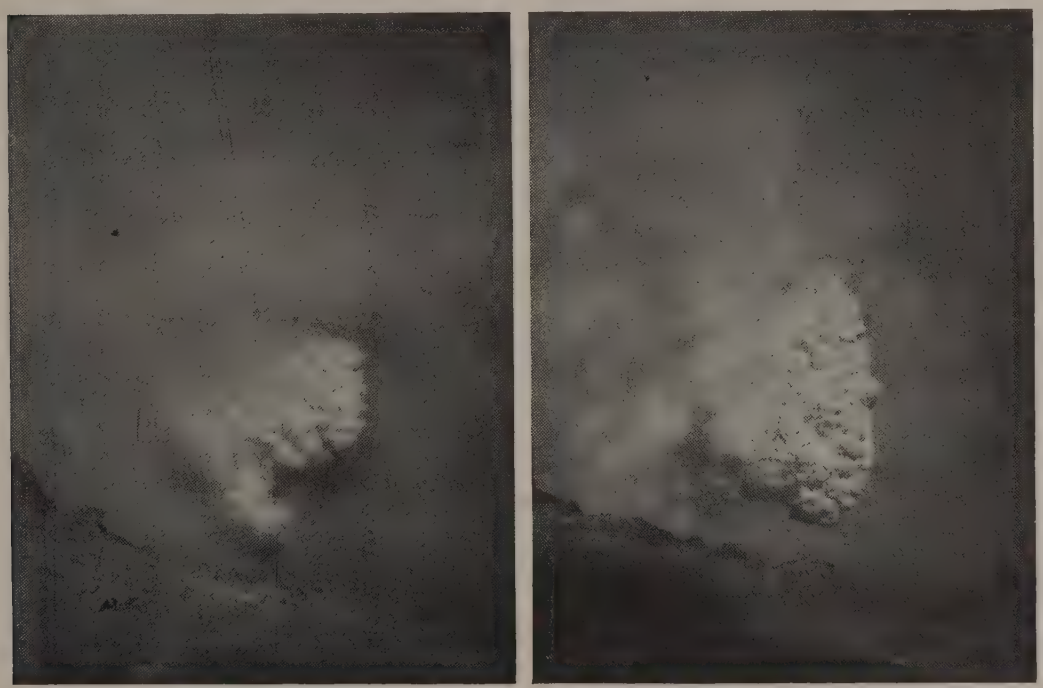


Fig. 60.—Development of a "cauliflower" ash-cloud formed by fall of avalanche material within the crater.

times a mass became detached (as the result of a seismic tremor, heating in the sun, or through undermining by water or gas) and fell with a roar into the abyss. When the amount of material was large, the air would be compressed beneath the falling mass, and an ash-cloud, differing in no respect from that produced by a feeble explosion, would be projected above the crater (Plate 14).

The word "avalanche" is here used instead of "dry slip," or other designation, as conveying a more adequate idea of the grandeur of the phenomenon. Detachment sometimes took place silently, but more often with a sharp crack, and the acceleration was virtually equal to that of a freely falling body. Huge boulders, rebounding from the sills of lava, would be projected horizontally and then descend in graceful curves, while the bulk of the avalanche, enveloped in whirling clouds,

fell from precipice to precipice with the reverberating roar of thunder, finally precipitating itself upon a talus at the crater-bottom. Then ensued the development of a magnificent dust-cloud, flaring and torchlike at the beginning, but soon forming a compact "cauliflower" cloud of exquisite beauty (Fig. 60).

The motion of translation and also of development was exceedingly rapid and the cloud expanded and advanced with sharply defined contours. As there were here no water vapor, no high temperature, and little if any electrical potential, it would seem that all that is required for producing sharp outlines in a dust-cloud is sufficiently rapid projection.

It was mainly because of these internal collapses that the more easterly parts of the crater-rim were so greatly reduced in height after the eruption and the crater itself increased in diameter, while in certain other directions inequalities in its walls were greatly accentuated. This was notably the case with the great northwest spur (Plate 15, A), upon the farther side of which an avalanche is seen descending in Plate 15, B. A typical example of downfall from the almost vertical sides of the crater is shown in Plate 15, C, where the scar of detachment may be seen above the talus conoid of fallen material.

The crumbling of the crater edge would also sometimes start a small avalanche upon the outer slope of the cone, and it was interesting to observe the sluggishness of these as compared with their great mobility during the eruption, when the same materials were hot and dilated with the interstitial gas and air (p. 89).

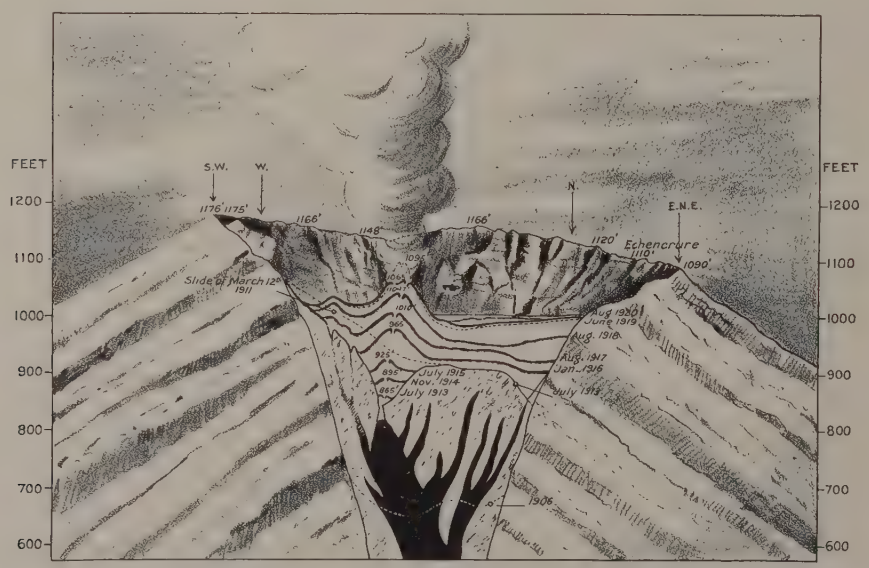


Fig. 61.—Ideal section through the Vesuvian cone, from southwest to northeast, showing the progressive filling of the crater from 1906 to 1920. The lower, dotted portion is material derived from internal avalanches, which extended up to the dotted line at the left. The crater floor and the eruptive conelet at successive dates are shown by heavy outlines. The solid black areas, representing the main conduit and tongues of lava, are hypothetical. Drawing by Malladra.

Views of the eastern end of the Atrio del Cavallo, before and after the eruption, showing filling of the region and obliteration of features by material brought down by hot avalanches and mud-flows.

The greatest of all the many internal avalanches resulted, on March 12, 1911,[1] from a collapse of the northwest crater-rim, which had been left by the eruption as the highest point of the cone (1,223 meters), as shown in Plate 17, A. By June of 1909 a "battery" of fumaroles had formed along the inner edge of this part of the crater-wall (Plate 17, B). The powerful undermining and excavating effect of their continuous exhalations was not duly considered by the engineers of the funicular railway, who located the new upper station on the outer side of this elevation at a point on the outer slope about 50 meters below the summit. On the date mentioned, the entire salient, 600 meters in length and 40 meters in maximum depth, precipitated itself inward as a veritable landslide whose materials formed a talus conoid extending far out upon and indeed covering the crater-floor, the funicular station being left on the edge (Fig. 63). This talus most deeply covered the southwest sector of the crater-bottom, under which the magma in the conduit was eating its way upward, and it was in the base of this conoid that those conical depressions were formed which eventually opened the way to a clear and free

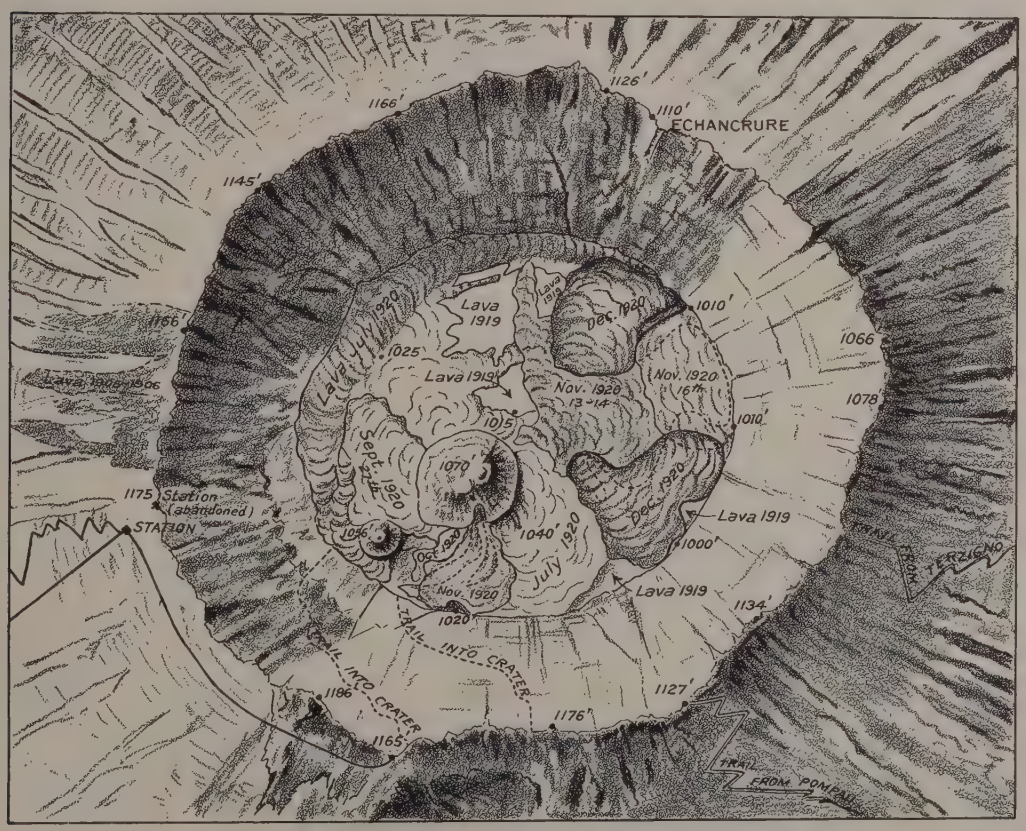


Fig. 62.—Map of crater floor on December 31, 1920. From Malladra.

[1] G. Mercalli, *Sopra un recente sprofondamento avvenuto nel cratere del Vesuvio;* Rend. Accad. Sci. Napoli, 1913, A. Mal'adra, *Sulle modificazioni del Vesuvio dopo il 1906;* Boll. Soc. Geogr. Ital., 1914, p. 1239; O. de Fiore, *Il periodo di riposo del Vesuvio, etc.;* Mem. Accad. Sci. Napoli, *15*, p. 32, 1914. Malladra and de Fiore give sections.

communication with the exterior, and thus started the new period of external activity.

It is very probable that, in intimate connection with this downfall, a subsidence of the crater-floor beneath it occurred, with engulfment of a considerable portion of its mass. This phenomenon of "internal avalanches" was most in evidence during the summer, autumn, and winter of 1906 and 1907, the autumn of 1908, the winter and summer of 1909, the summer of 1910, and the spring of 1911. It was through these downfalls of cone material that the abyss was filled, forming that obstructing plug whose subsequent final perforation has terminated this interval of repose.

The "internal avalanche," therefore, among all the features of this period, must be considered as the greatest damper to real volcanic manifestation.

We touch here the lowest point in the activity of the entire eruptive cycle (diagram 3 b), (cf. p. 142).

[A general idea of the condition of the interior of the cone is given in Fig. 61 (by Malladra), which represents the gradual filling up of the crater. The portion below the dotted line is, roughly, the material, derived from avalanches, that has filled the lower part of the crater. In this, toward the left (southwest), occurred most of the subsidences and the subsequent gradually rising eruptive conelet. The solid black tongues, representing rising lava, are hypothetical. H. S. W.]

THE MUD-FLOWS.

Mention has been made of heavy rain having fallen on April 27 and of the consequent formation, on the following day, of a "mud-lava," which, by invading inhabited localities, caused considerable damage to property—in this case principally to the Circumvesuvian railway, near Cercola. The phenomenon—frequently repeated during the following months—constituted a most destructive post-eruption feature, and its mode of action, although exceedingly simple, will now be discussed.

It will be recalled that, during the period of the eruption, an immense quantity of detrital material was removed from the upper slopes of the cone through the falling of hot avalanches. The ash, sand, and boulders were in no case, however, carried more than 3 or 4 kilometers from the volcanic axis, and they remained, consequently, upon the slopes of the mountain. Rain or snow would then soak the porous mass until a certain consistency was reached, which conferred a degree of mobility differing widely in character from that of the hot avalanche, but nevertheless permitting rapid descent through gullies and other natural depressions as a torrent of liquid mud. This carried blocks and boulders of all sizes and constituted, through its volume and momentum, a peril second only to that of the lava-flows.

The beginning of these streams of mud was often seemingly insignificant and sometimes the soaking would be discontinued, so that there resulted a mud-flow self-arrested for lack of material and hardened, as shown in Fig. 64. The plano-convex cross-section here seen was naturally less and less evident in the case of mixtures having a proportionately greater degree of fluidity resulting from a larger content of water, and in their fullest and most destructive development the surface conformation was virtually that of a thin fluid.

Pseudo-explosion at the crater caused by internal avalanches.

When, after long-continued soaking, the peculiar qualities of this material were most fully developed, the result was a sort of slimy and yielding clay, slow of flow in small amounts, but exceedingly mobile when in large quantity. Although it yielded readily underfoot, a large mass of the surrounding material would also be set in motion, and the writer can not recall a more difficult and dangerous excursion (p. 56) than that on the mud-besmeared crest of Monte Somma on April 29, at the close of the eruption. Neither alpine height, nor crater depth, nor any other mountain feature has ever held for him the breathless insecurity of that perfidious, unstable ooze.

When dry, the material tends to compactness and rigidity of form, but without cementation, although after repeated wetting, in contact with air, the surface layers acquire a degree of coherence that renders them fairly impervious to further infiltration of water. This feature was not without importance in its function of blanketing the gases, as we shall see in our subsequent study of fumaroles (p. 113).

Fig. 63.—Upper station of the funicular railway, constructed after the eruption at a point 50 meters below the crater-rim, but left standing on the brink by the great landslide of March 12, 1911. Photographed July 11, 1912. Only the portion beyond the crack at the right was standing in 1922.

During the month of May 1906 there were two further great invasions of cultivated and inhabited land, causing the death of two persons; and the autumn rains of the same year brought renewed disaster. In January 1907 and in the autumn of that year, in April of 1908, and more especially during the latter part of October 1908, the cities along the southwest base of the mountain suffered so much damage that the authorities caused to be constructed upon the mountain-side many stone dams designed to retain the material or, at least, to break the force of its descent by subdivision—an intent which has been in great part successful.

The mud of the lakes that resulted from these dams cracked in two directions, producing quadrangular forms (Fig. 65). Later, when the material had become so compacted as to permit surface drainage on the slopes, aqueous erosion produced innumerable arborescent trickle-patterns of great beauty (Fig. 66), as well as delicate traceries due to the deposition of sediment (Plate 16).

As the transportation and reaccumulation of chaotic material through the agency of the "hot avalanches" resulted in the forming of breccias, so, by analogous process, the mud-flows massed their heterogeneous contents into conglomerates, to the study of which Lacroix has devoted a paper.[1]

[1] A. Lacroix, *Contribution à l'étude des brèches et des conglomèrats volcaniques;* Bull. Soc. Géol., France (4), *6*, 635, 1906.

As a gravitational post-eruption phenomenon, the "mud-flow" was the external counterpart of the "internal avalanche," each tending to carry over, as it were, into the period of repose an illusion of vitality through a form of pseudo-activity destined, however, to give place to that quiet, although more truly volcanic, manifestation, the fumarole, which becomes our next subject for consideration.

THE FUMAROLES.

Before entering upon a discussion of this interesting subject, the writer feels bound to express his conviction that no other line of volcanic research is more in need of special attention. Since what may be called the classic foundations laid by Ste. Claire Deville, Fouqué, and Silvestri, a great amount of work has been done,

Fig. 64.—Lower end of a small viscous mud-flow.

but without that continuity of observation essential to so complex a study. Much of the interest has centered upon the analysis of the products without a corresponding study of the development of the fumaroles themselves. The problems are physical as well as chemical, and although new substances have been revealed, our knowledge of the hidden processes of fumarolic activity has made but little progress in half a century. The writer trusts that some investigator may yet specialize in this branch of study—one who will be a field-worker, collector, observer, and analytical chemist. The subject in general can not be taken up in this place, and its consideration here must be limited to a brief study of the fumarolic activity which at Vesuvius constituted the most significant index of the volcano's real condition during the long period of external repose.

We begin with one detail of the utmost importance. Except under certain conditions, of very brief duration in time, the vapor of water forms one of the chief constituents of fumarolic exhalation, and the white cloud of its condensation constitutes the most clearly visible index of the fumarole's state of activity. But

A B C

Views of internal avalanches. A, spurs projecting internally from northwest crater-wall; B, descent of a small avalanche in a runway behind the spur shown in A; C, fall of a small internal avalanche, showing the scar of detachment (above) from crater-wall.

the extent to which condensation takes place is variable, depending mainly upon the humidity and temperature of the surrounding air and its consequent capacity for absorption, the temperature of the vapor at the moment of emission, and the presence of nuclei favoring condensation.[1]

It will thus be obvious that, unless such factors are taken into consideration, the visual appraisal of fumarolic activity may frequently be erroneous. The vapor of water issuing in abundance at a temperature of several hundred degrees into an atmosphere with but 30 per cent of humidity, in clear sunshine and a brisk wind, may be fully absorbed and dissipated without a trace of visible condensation (Fig. 67). When experimenting at the Solfatara, the writer found that by artificially heating the walls of an orifice the issuing vapor was absorbed without con-

Fig. 65.—Shrinkage cracks in mud collected above a dam.

densation in spite of artificial injection of nuclei, which otherwise precipitated a dense, white cloud. Fumarolic observation thus requires judgment and experience, the possibility of error being fully as great as, and analogous to, that in seismometric indication of negative forms of volcanic activity, e. g., the contractile effects of cooling injected lava.

In the broadest etiological sense, fumaroles may be classified as belonging to the *primary* or the *secondary* type.

Primary fumaroles are those which are formed over fissures in the mountain mass and which are fed directly from the main source of activity, and may thus give (through variations of temperature, the nature of their products, and the volume of their exhalations) a true index of internal conditions. Strictly speaking, therefore, such fumaroles constitute a real, though moderate, form of endogenous

[1] Nucleation may not only cause the condensation of water vapor from volcanic vents, but nuclei from the vents may cause condensation of *atmospheric* vapor and give the illusion of a copious emission of vapor from a crater. The writer observed this at Stromboli in 1915. (Perret, *The lava eruption at Stromboli, 1915.* Am. Jour. Sci., *42*, 462, 1916.)

activity and, when present, the term "repose period" should be taken in a relative sense, as indicating a lack of the more violent activity manifested through the main conduit.

As in all cases of classification, great care will be needed in the diagnosis—not because of any indefiniteness regarding the types themselves, but by reason of a certain difficulty in discerning the conditions of their formation and function. Thus, a fissure in the main cone may have been filled and completely sealed with injected lava of the last eruption, and the fumaroles upon it—which may possibly have been adjudged *primary*—can but be supplied by the emanations of the detached and cooling mass, and will rightly pertain, in consequence, to the *secondary* class. Again, a true and open fissure may become choked with the infiltrating

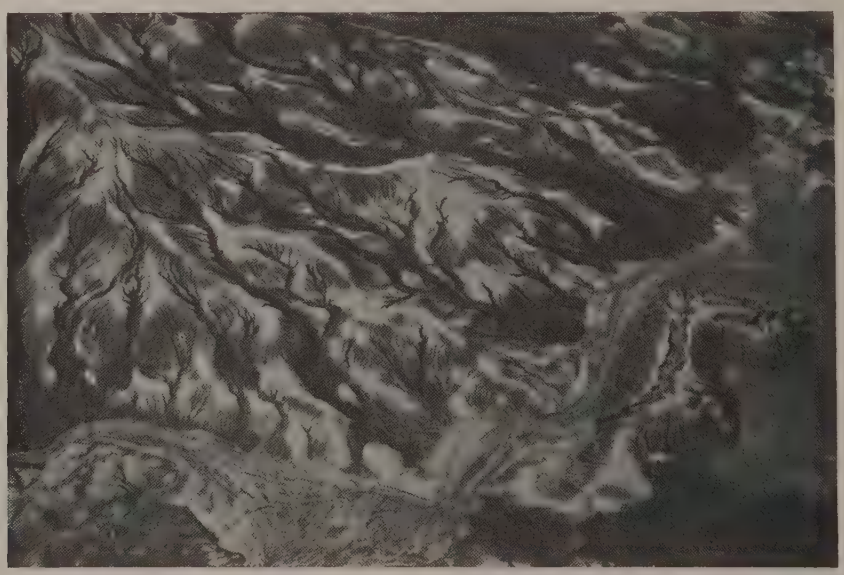


Fig. 66.—Trickle patterns produced by water erosion on ash-fields of the Atrio de Cavallo.

products of erosion, or virtually closed by a settling of the cone, and its straitened channel may be abandoned by the gases, which will have found another path of less resistance. In such cases the temperature gradient of the exhalations will be a descending one, even though the volcano's activity may actually be increasing. Several of these anomalies were present in the fumarolic manifestations during this long period of external repose.

Secondary fumaroles are those which develop upon lava streams at a distance from their source, or even upon accumulations of clastic ejectamenta. These, consequently, have no connection with eruptive channels within the volcano, but are isolated and limited in their exhalations to the contents of the mass of material upon which they have been formed, with, in some cases, distillations from the underlying terrane. They may, and often do, show the whole range of fumarolic emanations, from the neutral, high-temperature exhalation depositing alkali chlorides, down through those of aqueous acid vapors with deposition of metallic

Delicate traceries of sediment produced by drainage on mud deposits in the Atrio del Cavallo

chlorides and sulphates, to the emanation of hydrogen sulphide, with sulphur and sulphides, carbon dioxide, water vapor, and hot air. But this transformation is generally comparatively rapid and the temperature gradient (except for temporary variations) will be consistently downward. The life of such fumaroles will perforce, for the reasons given, be more or less transitory.

The habit of emplacement of secondary fumaroles upon the lava-flows often follows stream-lines and the zone of contact with the lateral moraine, although frequently they will be found grouped in certain portions of a lava field, while other areas on the same mass of material, equally broken in surface, show no loci of gaseous emanation. One explanation may be found in the observation by the writer that there is a remarkable permanence in location centers of gas-emission which had begun by explosion at the time of the outflow of the lava, or even during the segregation within the volcano. It is as though a strong gaseous outburst started an influx from all sides to the explosion center, which then continues to act as the gas-vent of the surrounding material, and this may readily be supposed to constitute a fumarole, or fumarolic group, after the lava has solidified. At Etna, in 1910, columns of vapor that continued to issue from definite spots on the rapidly flowing lava stream demonstrated the peculiar permanence of these loci of emission, formed originally by explosion.[1]

Fig. 67.—Collecting gas from a high-temperature (430°) fumarole on north flank of the cone.

It will be evident that fumaroles of the secondary type, being unconnected with the volcano's eruptive channels, can not serve as indicators of its activity.

PRIMARY FUMAROLES.

As has been pointed out already, the true primary fumaroles constitute, during the greater part of a repose period, one of the few outward and visible signs of the

[1] A similar localization of fumaroles on moving lava-flows during the eruption of 1872 was noted and commented on by Palmieri, *The eruption of Vesuvius in 1872;* London, 1873, p. 92. (H. S. W.)

volcano's real, although hidden, continuation of activity, and it goes without saying that continuous, systematic observations at such vents would be prolific of results. To the difficulties already mentioned regarding immediate determination of the specific nature of the fumarole and its possible deterioration through obstruction of the channel, there is often added the destructiveness of the mineral-hunter, whose excavations prevent the continued use of a pyrometer in the same spot for comparative measurements and often fill and obstruct the cavity, with resultant deviation of the gas elsewhere (p. 106), this sometimes even bringing about an alteration in the products of sublimation. Notwithstanding such impediments, the study of these fumaroles formed an important line of field-work during this period, although it was carried on with less continuity than was desirable because of work at volcanoes in other parts of the world.

Immediately after the eruption no primary fumaroles were seen upon the mountain, this condition being due to temporary exhaustion, to the clogging of internal channels, and to the mantle of detritus upon the edifice.

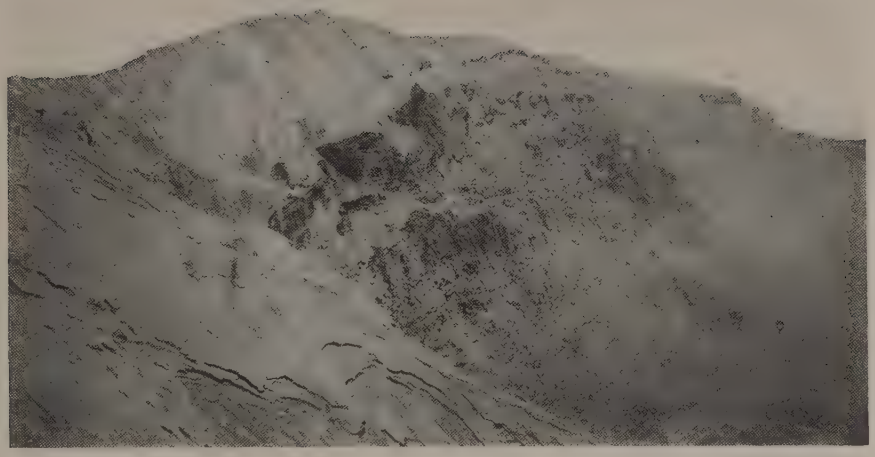
Successive views in Plate 17 show the development of a battery of vents on the inner northwest wall of the crater, the inaccessibility of which has prevented collection and analysis of their products, but whose instrumentality in causing the great downfall of March 12, 1911, has given them a place of interest among the phenomena of the "repose period."

Of the fumaroles, supposedly primary, at the vents of the southeast lavas of the recent eruption, it may be said that their principal emanations were acid, with a prevalence of ferric chloride in the deposits and the formation of hematite, and that their activity was comparatively short-lived—the type not being, probably, purely primary, but conveying the exhalations of the hot lava that still remained in the tunnels and which virtually sealed the original fissures (p. 106). One of these vents, about 100 meters below the crater's edge, still exhaled, on July 10, 1909, neutral gases having a temperature of 235°, and another just inside the crater yielded hydrogen chloride abundantly, without a trace of sulphur dioxide, at a temperature of 160° C.

Far more important and definitely typical were the primary fumaroles that formed upon a series of fissures in the sector of the cone, coinciding in a general sense with the "échancrure," but lying, more exactly, a little to the east and west of its radius. Early in 1908 these showed temperatures, accurately measured by electric pyrometer, as high as 323° C., eventually reaching 438°. The emanations were generally acid, with hydrogen chloride and sulphur dioxide, and accompanied by the usual high-temperature deposits. Boric acid was produced, in considerable quantity, from one vent, with a temperature of 160°, from 1908 to 1914.

An aspirating pump was used for collecting the gases (Fig. 67), as the vent was too large to permit fitting the tube into it closely, although the pressure was high. Dr. Henze, of the Naples Zoological Station, found in the gas sample 81.7 to 81.6 per cent of nitrogen and 18.3 to 18.4 per cent of oxygen, which are about the proportions in air, with small amounts of water vapor and hydrochloric acid, the last detectable on the spot. This fumarole had, by July 1, 1909, through the force

A



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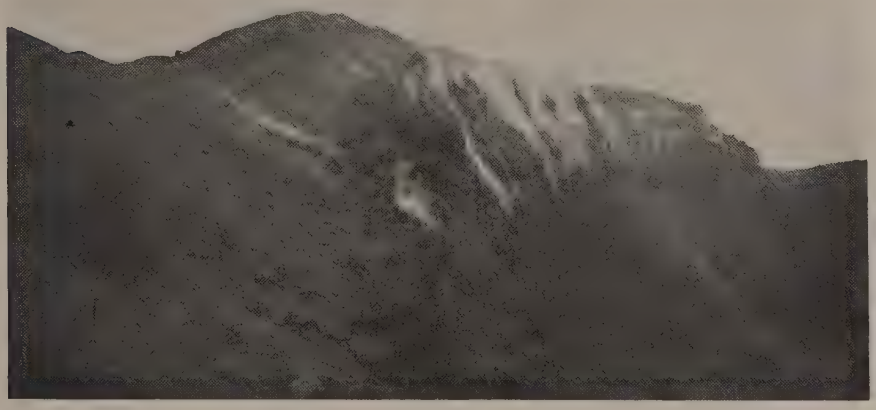

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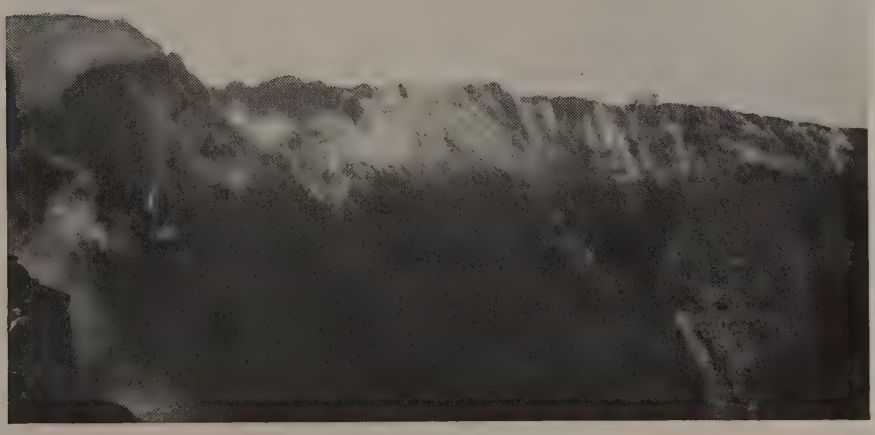

Views of internal northwest crater-wall.

A, the wall on July 1, 1906 (note entire absence of fumaroles).

B, same locality on June 5, 1909, showing development of fumaroles whose undermining effect caused the great landslide of March 12, 1911.

C, same locality on March 21, 1911, after landslide, showing upper funicular station at new edge of crater.

and volume of its exhalations, enlarged itself into a grotto 2 meters long, upon the inner end wall of which had been deposited a white substance in the form of small cascades and stalactites. This substance was soluble in water and Dr. Henze found that it contained sodium, potassium, and magnesium, with traces of aluminum and calcium; the negative radical was chiefly hydrochloric acid, with a little sulphuric and a trace of hydrofluoric acids.

This particular vent, in the subsequent investigations by the Observatory staff, was designated as "Fumarola A," while another, "B," at a slightly greater altitude, was more commonly called the "Fumarola Perret," although most of the writer's work was done at fumarole A. At the end of the summer of 1909 the grotto was practically ruined by mineral-hunters, but the gas-pressure (often sufficient to produce a shrill, continuous whistling sound) generally recleared the channel, with renewed increase of temperature. The opening of the main volcanic conduit in 1913 (p. 121) deprived these passages of their high-pressure supply, and with the close of the "repose period" their usefulness was at an end.

SECONDARY FUMAROLES.

The shallowness of the rapid lava-flows of the great eruption on the southeast flank of the mountain rendered very short-lived the secondary fumaroles which formed upon it. They passed rapidly through the various phases of exhalation, with predominant deposition of ammonium chloride, whose increasing prevalence on those portions of the streams farthest from their source lends probability to the hypothesis that this compound resulted from the nitrogenous materials (i. e., vegetation) encountered en route,[1] though there can be no doubt of its frequent presence in the original magma. Sulphur was deposited in small amount, and the presence of fluorine was determined.

The secondary fumaroles of the subterminal lava-flows of 1905–6, on the west-southwest flank of the cone (p. 25), although longer-lived as regards their temperature, were also comparatively uninstructive in their sublimations, depositing chlorides and sulphates up to the spring of 1909, after which time the emission was mainly of heated air. In April 1907, Mercalli was able to fuse lead wires but not wires of zinc, this indicating a temperature between 325° and 412° C. In February 1908, wires of tin were fused but not wires of lead, indicating a temperature between 228° and 325° C. On March 5, 1908, with an electric pyrometer (p. 134), the writer observed the temperature of 244° C. at the same spot. At another point, where the lava had greater depth and the fumarole was thickly incrusted with sublimations, the temperature in July 1909 was 175° C.

For a number of years after the eruption, numerous spots that maintained a certain temperature amidst clastic ejecta, as well as upon the lava fields, emitted spiracles of water vapor after each fall of rain. These constituted, through their longevity and persistent vitality, what might almost be designated as a *tertiary* type. The writer has also noted that upon the ash-covered cone a fall of snow was far more efficacious than rain in the development of these steam jets, by reason of the

[1] Palmieri (*The eruption of Vesuvius in 1872;* London, 1873, p. 137) states that abundant sal-ammoniac is "only found on the fumaroles of those lavas which have covered cultivated or wooded ground." (H. S. W.)

gradual melting and prolonged seeping into the deeper layers of the porous mass, whereas much of a heavy rain would run off in a mere surface drainage. An aspect of the cone with these emanations resulting from the melting of snow is presented in Fig. 68.

THE YELLOW FUMAROLE.

The greatest and most typically "primary" vent of all those of the "repose period" was that known as the "Fumarola gialla" (the "Yellow Fumarole"), so called because of the brilliant coloration of its deposits. It was not, properly speaking, one vent, but formed a series of openings along the line of a compound vertical fracture in the western inner wall of the crater, often visible throughout a considerable portion of its length, and in direct communication with the volcanic

Fig. 68.—Great fumarolic activity on sides of the ash-covered cone consequent upon infiltration from melting snow.

chimney below the plug that obstructed it. A general view of the locality and of its development is given in Plate 18.

At the time of the writer's first descent (p. 122), in August 1916, the temperature was 260°[3], having risen from 128° at the time of the first measurement (by Capello) in September 1911, whereas it was 295° in May 1912, 330° in September 1913, and 347° in October 1913, as measured by Malladra.[1] In 1917 it had fallen to 220° (p. 131). During the visit to the bottom of the crater in August 1916, the water of condensation from the "Yellow Fumarole" was collected in a receiver through a curved glass tube, the distillation being allowed to continue for 12 hours. This yielded about one-third of a liter of water, which was analyzed by De Luise with the following results: SO_2, 10.30; HCl, 2.67; HF, 0.01; H_2O, 97.00; total, 99.98. An analysis by Bernardini of the gas from this fumarole in 1913 showed much sulphur dioxide, with hydrochloric acid and carbon dioxide, some oxygen, and much nitrogen.[2] Carbon monoxide, hydrogen, and hydrocarbons were absent.

[1] A. Malladra, 3, p. 6. [2] A. Malladra, 3, p. 7. [3] Thus in Perret's MS., but this differs from his statement on p. 122.

Progressive development of the "Yellow Fumarole."

In 1916 hydrofluoric acid was present in sufficient quantity to corrode the front lens (p. 122), of the writer's cinema objective, and the emanations from this principal primary vent constituted, for the earlier investigators, the most serious inconvenience in the descent into the crater.

The other fumaroles within the crater, although they were indisputably of the primary type and were frequently active, were strangely low in temperature. Malladra observed temperatures of from 75° to 96° in 1912, although hydrochloric acid and sulphur dioxide were abundant.

But the crateral fumaroles of the new active period, which formed upon the erupted lavas that constitute the floor of the crater, were and are of very high order of chemical activity. Only the dry, neutral type, which deposits sodium and potassium chlorides, is lacking among them. Ammonium chloride (p. 123) was found during our descent in 1916 at a fumarole that had a temperature of 425° and which had formed three days previously upon recently erupted lava.

In table 2 are collected some data as to temperatures at various fumaroles within the crater and on some external lava-flows.

TABLE 2.—*Temperatures of Fumaroles at Vesuvius.*

Maxima of vents under échancrure:	
Mar. 5, 1908	344°
Sept. 3, 1908	435°
Mar. 30, 1909	420°
June 7, 1909	427°
June 13, 1909	438°
July 9, 1909	430°
July 20, 1909	416°
Aug. 14, 1909	420°
Mar. 11, 1910	335°
June 19, 1910	235°
Mar. 22, 1911, all reduced to 100°	
July 11, 1912	242°
Jan. 19, 1913	225°
Fumaroles upon the subterminal flows on southeast flank:	
Apr. 1907, between 325° and 412° (Mercalli)	
Feb. 1908, between 328° and 325° (Mercalli)	
Mar. 5, 1908	244°, 248°, 260° (Perret, pyrometer)
Sept. 1908	163°, 140° (Perret, pyrometer)
Apr. 1, 1909	172° (120° farther south)
June 13, 1909	155°
July 10, 1909	65°
July 1909	175° (different locality)
Fumaroles on the lava of 1906:	
Mar. 5, 1908	232°, 244°, 248°, 260°
Sept. 3, 1908	140°, 163°
July 10, 1909	235°
Aug. 14, 1909	160° fumarole with HCl

THE SOLFATARA IN THE ATRIO.

If the radius of the "échancrure" is extended to the base of Somma at the "Canale dell' Arena," a region is traversed where fumarolic activity existed for some time prior to the eruption. This area lies at the conjunction of the lavas of the cupola of 1903 and that of 1891 (Colle Margherita), which lavas had presented the phenomenon of "eruptive fumaroles," and is, moreover, in line with the fracture of 1834 (Fig. 69). The eruption, with its rain of detritus and deposition of material by hot avalanches and mud-lavas, greatly altered the topography of this region (Plate 13) and temporarily buried out of sight many of its most salient features with deposits up to 15 meters in depth. There remained, however, mud-coated domes corresponding with these vents—and doubtless resulting also from fresh fractures—forming a series of "montagnelle" or rounded "hornitos" (Plate 19 and Fig. 70). This group of aqueous fumaroles became known as the "Solfatara of the Atrio."[1] Immediately after the eruption the writer found fumarolic emanations from cracks in the ash-layers of this region 200 meters distant from the base of Somma with a uniform temperature of 98°, abundant water vapor, hydrogen sulphide, and deposits of sulphur in the cracks (Fig. 71). An analysis of the gas

[1] For descriptions of these fumaroles, see A. Malladra (2); L. Bernardini (1); Washington and Day (1).

by Dr. Henze gave:[1] H_2S, 11.47; CO_2, 2.08; O, 11.47; N, 74.98; total, 100.00. A qualitative analysis showed that the fumarolic salts contained aluminum, iron, and calcium, with sulphur trioxide and dioxide. At one vent there were abundant deposits of realgar.

Malladra and Bernardini subsequently divided this solfataric area into three groups, with increasing distances from the volcanic axis and the distinguishing characteristics of 7 to 12 per cent of H_2S and temperatures 97° to 98° in group I;

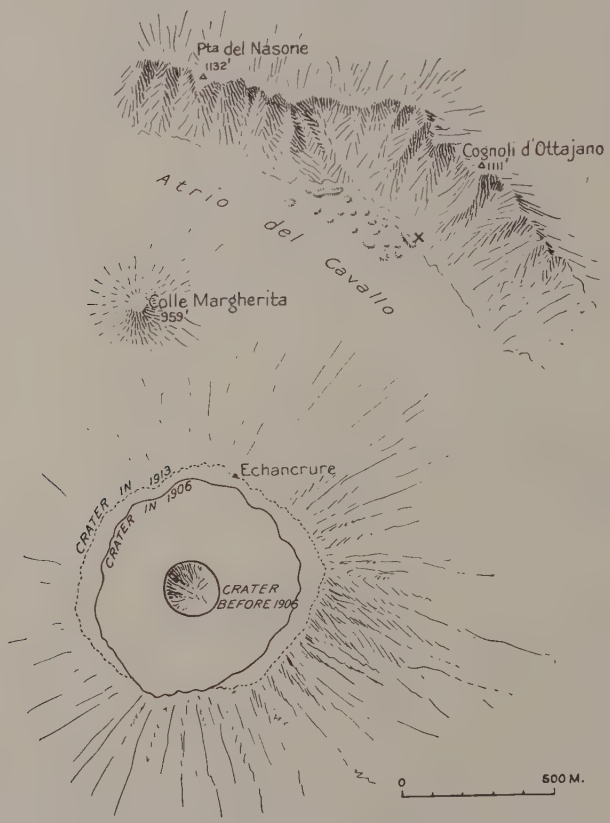

Fig. 69.—Map of crater and fumaroles at the Solfatara in the Atrio del Cavallo. From Malladra.

very little H_2S and temperatures 85° to 98° in group II; no H_2S and temperatures 60° to 98° in group III.

The superficial stratum of hardened mud (p. 103) formed a nearly impervious layer that effectively blanketed the upwardly diffusing gases, which were in some places deflected to the edges of the sheet in contact with the Monte Somma wall, with fumarolic issue at those points, as at a dike in the Monte Somma wall from a longitudinal crack whence warm steam was issuing in June 1914 (Fig. 72).

A recent visit to the locality of the Solfatara (August 1921) shows that the condition of many of the vents is quite unchanged, but with a greatly advanced denudation of the little edifices by aqueous erosion.

[1] F. A. Perret (1), p. 423.

Solfatara in the Atrio del Cavallo, June 1914. Photograph by A. L. Day.

SUBSIDENCE PHENOMENA.

We have seen that, as a result of internal avalanches, the crater-bottom gradually rose, by the process of filling from above, to a level whose lowest point, in September 1911, was at an elevation of 944 meters above the sea, and whose greatest inequality in height was an enormous talus conoid resulting from a downfall of the southwest rim of the crater. But a new process had already begun, a series of subsidences on the crater-floor, which for a time not only checked all upward growth, but very considerably lowered its level in certain localities (cf. Fig. 61). These collapses, together with the rise in temperature of the primary fumaroles, constituted a sure indication that the magma was rising in the conduit and had already reached such a height that its gas-emitting tongues were excavating the materials of the obstructing plug in proximity to its upper surface, so that occasionally these would precipitate into an underlying void or pool.

The *modus operandi* of a rising magma in eating its way through an obstruction formed of comparatively loose material is now believed to be fairly well understood.[1] The principal boring agent is the gas-headed lava column, and the gravitational adjustment between the gas and the liquid in the lava column determines the upward progression. The magmatic column may have a temperature sufficient to re-fuse the material engulfed by this process of stoping, and heat will be maintained through gas-reaction, convection currents, etc. But the excess of heat will not generally be sufficient to melt the containing walls to any great extent; otherwise the conduit would continually widen and the volcanic edifice would cease to exist. The average condition is probably the converse of this, and often there is formed, by congelation of hot lava upon the cooler walls, a layer of viscous, semi-solid material which the writer has called the "*plastic lining.*"

But in the process of gaseous excavation above the magma column the liquid (except during a collapse of overlying material) rises into a clear space. This is of great importance in showing that (as there is no solid obstacle to a more rapid uprising of the lava in the conduit) its extreme slowness of ascent is due simply and solely to the slow rate of supply of lava from the depths, this being probably caused by great viscosity at lower levels or possibly by slow absorption of water or other gases essential to its expansion.

There comes a time when the rising magma reaches a point when its engulfment of overlying materials will affect surface conditions and cause subsidence of the crater-floor. During the period we are considering, very considerable lowering of the surface was produced in widely separated places, indicating that several tongues of magma or (at least) localized gas-channels leading from a central mass of magma not far below were melting the great plug. The development of numerous primary fumaroles, some of considerable power, at the bottom of these sunken areas completes the evidence.

The first of these subsidences was discovered by the writer on June 19, 1910, in the materials of a landslip at the base of the southwest wall of the crater; but insa-

[1] F. A. Perret, *The ascent of lava;* Am. Jour. Sci., *36*, 605, 1913; Daly, *Igneous Rocks and their Origin*, 274, 1914.

much as this collapse had been accompanied by explosive phenomena, it is difficult to assign cause and effect. There had been formed, as shown in Fig. 72, a cone of ejected material surmounted by a small crater and partly surrounded by a concentric ring of larger dimensions, and this was situated within a collapsed area whose confines are clearly shown in the photograph. According to the guides, explosive activity was observed in this locality on May 27 and 28, 1910.

Was this the result of primary activity reaching the surface at this point and causing, by the shock of explosion, a subsidence of the surrounding material? Or was it simply the collapse of this material into an underlying excavated pocket, with consequent air compression and a blowing up through the mass, thus forming the cone of ejection? Or was there local gas generation through infiltration of water

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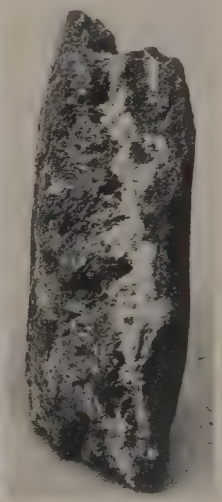

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Fig. 70.—Two of the "montagnelle" (hornitos) at the Solfatara in the Atrio del Cavallo.
Fig. 71.—Specimen of ash deposit, with sulphur-filled crack (white), from the Solfatara.

to the heated region below the adjacent fumaroles? The last of these hypotheses may be the true explanation, although many considerations favor the first, especially the fact that it was in this general locality, the southwest sector of the crater, that the volcanic conduit eventually opened to the surface. At all events, this explosive collapse apparently constituted the first visible manifestation of renewed dynamic activity, and this was soon followed by the greater subsidence, which will now be described in detail.[1]

That which, in all probability, was the second subsidence, and by far the most important of all, occurred in connection with the great southwest landslide of March 12, 1911. The subsidence has been overshadowed by that spectacular event, whose

[1] Perret does not state the exact locality of the first subsidence (June 19, 1910). It was in the neighborhood of that of March 12, 1911, and the foci of the two were very possibly coincident, as there is some evidence that this part of the crater-floor is the site of the upper end of a gas-fluxed pipe that has persisted for many years. The two subsidences, on this hypothesis, would be the result of the blowpiping action of the head of the slowly rising lava column, ending eventually in the free escape of gas and lava. The persistence in place of the small and gradually growing eruptive conelet (described in subsequent pages), the ejecta from which have slowly filled up the crater, supports this explanation. (See R. A. Daly, *Igneous Rocks*, 1914, pp. 251 ff.; and H. S. Washington, *Persistence of vents at Stromboli and its bearing on volcanic mechanism*, Bull. Geol. Soc. Amer., *28*, 271, 1917. (H. S. W.)

more superficial manifestation buried out of sight all traces of the subsurface phenomenon. On the basis of a calculation by Civil Engineer Treiber, the mass of collapsed material within the crater was found to be smaller than the cubic dimensions of the detached portion of the wall, and we may suppose either that the weight of the landslide, combined with the momentum of its descent, hastened the collapse of the crater-bottom into the subjacent conduit, with consequent engulfment of

Fig. 72.—Dike in wall of Monte Somma, with steam issuing from near its base and from a longitudinal crack. June 1914. Photograph by A. L. Day.

much of its material, the resultant depression being then filled by the rest of the slide; or else that the subsidence was itself the determining cause of the detachment of the crest, already undermined, as we have shown, by fumarolic activity (p. 101).

However, the existence in this case of a real collapse into the conduit is, in the writer's opinion, attested by a most interesting and suggestive phenomenon:

an immediate and very considerable decrease in the exhalations of the primary fumaroles communicating directly with the central source. This diminution in the activity of many of the fumaroles upon the crater-floor may have been due to a blocking of their channels through a shearing movement of the mass of subsiding material, or even to actual burial of the vents under the mass of the slide.

But this explanation will not apply to others beyond such a sphere of movement. The writer is convinced that another and more profound cause is involved. This is the chilling of the lava by the precipitated mass of cold material. The immersion of this tends to check for a time the effervescence of the liquid, and there-

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Fig. 73.—Small cone (x) with a "somma" inclosing it, at base of southwest internal wall of crater. The surrounding area of collapse is visible.

Fig. 74.—The subsidence, of January 21, 1912, in the southwest talus conoid; seen from the north on July 11, 1912.

fore the active emission of gas, with consequent diminution of fumarolic activity at all the vents directly connected with it. The condition will be temporary, with subsequent gradual increase of the thermal, chemical, and mechanical activity of the magma as the solid material is attacked, dissolved, and fused, until bubbling is resumed and gas is again given off.

The writer is the more fully convinced that this chilling effect is a cause of the fumarolic diminution, because he observed the process several times, and under peculiarly favorable circumstances, during his stay at the crater of Kilauea. When the lava-lake was in full activity and continuously fountaining in many places, an avalanche from the sides of the pit, precipitating a mass of broken rock into the

liquid lava, would cause immediate and complete cessation of all effervescence, the lake remaining perfectly quiet for hours. A similar effect was produced by the sinking of a rocky mass forming an island. As the comparatively cool upper portion became immersed, all outward activity ceased, and only a gentle, simmering sound attested the lava's attack upon the newly submerged material. To use a homely simile, this chilling process is analogous in effect to the placing of cold eggs in boiling water, but the quantity of lava affected is extraordinary and reveals how sensitive is the thermal cause of effervescence.

In the case of the landslide under consideration, and its assumed partial subsidence into the lava, the writer found on March 21, nine days after the landslide, that the temperature of the external fumaroles upon the northern flank, which regularly exceeded 300° C., was reduced to 100° C., water vapor being emitted. This great, although temporary, diminution in the activity of these vents was almost certainly due to the chilling process we have been considering. An obstruction at other vents would have but tended to produce increased activity at these. Al-

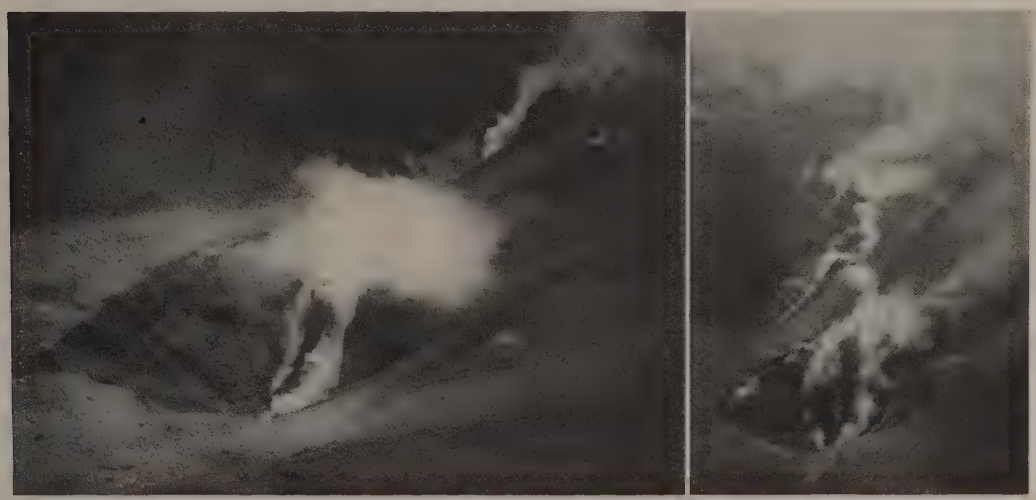

Fig. 75.—Subsidence of May 9–10, 1913, in the material of southwest landslide. There is no free opening.

though their feeding-channels tap the main supply at a considerable depth, as the writer and Malladra believe, nothing prohibits the temporary cessation, by chilling, of effervescence and gas-emission throughout the entire liquid mass.

The third subsidence, now to be considered, was effected so slowly that the material could be absorbed gradually without producing any marked effect upon the temperature of the magma. This slow sinking of the crater-bottom occurred during November at the base of the eastern wall and extended for a considerable distance north and south, forming a crescent-shaped depression some 35 meters in depth, with perhaps a sinking of as much as 60 meters below the center of the crater-floor. In this curved depression primary fumaroles were formed, often very active and exceedingly acid, but of moderate temperature.

The next notable subsidence was of great importance. It occurred on January 21, 1912, at noon, and was signalized by strong seismic and acoustic effects noted

at the Vesuvius Observatory and registered at that of Valle di Pompeii. The origin was again in the southwest sector—where it became increasingly evident that the conduit would eventually open to the surface—and beneath the talus that deeply covered that entire area. The conoid, as a result of this engulfment of a portion of its mass, descended bodily by as much as 30 meters, while the center of collapse was marked by an obliquely conical depression about 100 meters in diameter and 20 meters deep at first. This "funnel," somewhat altered in depth by sinking of the incoherent materials, is shown in Fig. 74, as photographed on July 11. No revelation of the subsurface activity described at the commencement of this section could be more striking than these hour-glass formations with their precipitation of material (as through a gigantic funnel) into an underlying void excavated over a rising column of liquid lava (cf. Fig. 75).

As in the former case, a diminution of fumarolic activity followed, especially on the crater-floor, where a central vent ceased activity, as well as most of those in the eastern crescentic depression. The primary fumaroles on the external north flank did not seem, at this time, to have been notably influenced and, although leaving a visible depression, the engulfment of cold material was probably slight as compared with the former case. This depression was eventually almost obliterated by the settling of the talus, but at about midnight of May 9–10 there occurred a still greater collapse of the same kind, forming a depression 150 meters in diameter and 75 meters deep. This subsidence, also, was preceded by many strong local earthshocks and caused a fall of ash. On the side toward the talus the downfall had left a vertical wall (seen in Fig. 75), and, in contrast with the previous collapses, a gas-vent was formed at the bottom of the conical pit; this, although it did not have a clear opening, permitted the passage of a large amount of vapor, forming a gigantic fumarole. The strongly acid gases were mostly hydrogen chloride and sulphur dioxide. This fact, with the repeated sinkings on this particular portion of the crater-floor and (above all) the formation here of a gas-transfusing vent, left little doubt as to the imminence of a final collapse which would leave a freely open conduit and begin a new period of open activity.

PART IV. THE NEW ERUPTIVE PERIOD, 1913-1921.

In the concluding portion of Part III we followed the various phenomena of subsidence at the crater-bottom until the formation (on May 9–10, 1913) of a large, conical, vapor-emitting depression ("funnel") at the base of the great southwest landslide (p. 118). During a subsequent visit to the crater, on June 26, 1913, the writer was particularly impressed by the extraordinary amount of hydro-

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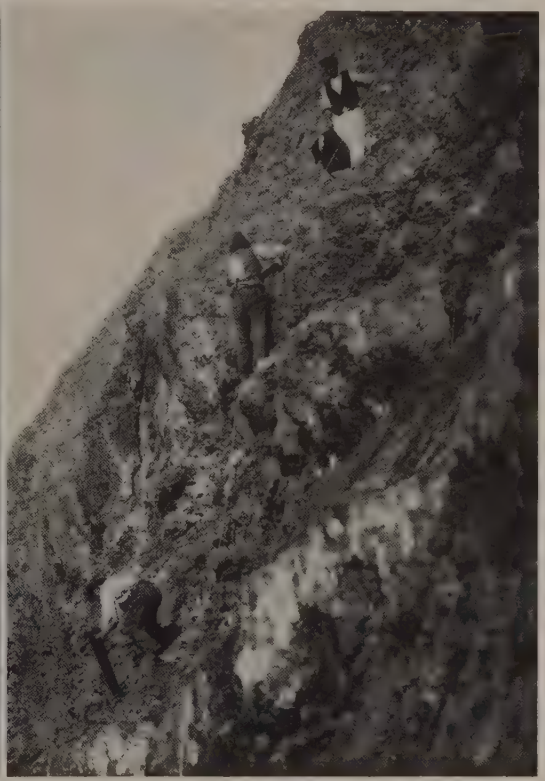

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Fig. 76.—Conical depression (imbuto) in July 1915, nearly filled with lava. Photo by Malladra.
Fig. 77.—Descent of the inner crater-wall on the southwest side, August 4, 1916.

gen chloride in the vapor rising from this vent, which seemingly presaged some greater manifestation of activity. On the morning of July 5 a wall of the conical depression was perforated, leaving a clear opening, within which could be heard and seen, at night, the familiar vibration and ruddy glare reflected from incandescent lava. After seven years of obstruction, the Vesuvian conduit had again attained the open condition that is normal to it in modern times and a new period of free external activity began. The subsequent progressive filling of the crater is shown in Fig. 61, page 100.

In the absence of direct observation, it can not be known whether this opening was formed by collapse, as in the preceding case of subsidence—and as might be inferred from the sharpness of its edges—or whether the material was blown upward by explosion of the compressed gases, at last in direct contact with the under side of an ever-thinning crust. Possibly neither phenomenon need be excluded, but in any case the collapsed material, if subsidence there were, was small in amount as compared with that of the downfalls that caused the great conical depressions. It is also probable that the greater portion was at once blown outward by the escaping vapors, as these were seen rising under forcible propulsion to a height of at least 600 meters above the summit of the mountain.

The upper edges of the vent were sharply defined and its lowermost lip was above the level of the center of the depression. The vapors, strongly charged with hydrogen chloride and sulphur dioxide, issued tumultuously from the vent in a series of rapidly recurrent, puffing vortices, indicating emission from lava that was in a state of violent effervescence but at the same time so liquid as to prevent explosion and upward projection of resistant material. The surface of the magma was evidently still far below the upper opening, although a reflection of color was suspected, even in daylight. The writer, visiting the crater at night on July 18, 1913, accompanied by Doctors Malladra and de Fiore, rejoiced once more in the old familiar lava-glow of a resuscitated Vesuvius. No magma was visible, but from the glare its temperature was estimated to be at not less than 1,200° C. There had been no overflow from the vent nor (apparently, at that time) any outward projection of scoriæ. The characteristic sound of liquid lava in ebullition was plainly audible and every indication was positive that the lava had an elevated temperature and a high degree of liquidity.

The writer must insist once more upon the importance of this fact of a column of exceedingly liquid lava standing quietly, at a comparatively low level and without obstruction, in an open conduit.

On July 24, 1913, explosive sounds were heard, the reflected glow being visible in full daylight, and on August 2, 3, and 4 the emission of vapor was accompanied by fine red ash, apparently indicating a disruption of the conduit-walls. Later, on August 5, the active magma was again cut off from free communication with the atmosphere by internal collapse of the conduit-walls, caused probably by a lowering of the lava column after its explosive discharges of the preceding days. Although some gas was being emitted, the vent did not clear for itself an opening until October.

Early in September 1913 Malladra,[1] with two Bavarian investigators, descended for the first time to the edge of the vent. He observed that its walls were incrusted with splashes of recent lava and found some fresh scoriæ scattered about upon the walls of the depression.

In October 1913 the vent again became clear of obstruction, with copious emission of gas, and for a whole year there was but little change, with the exception of a second opening in the depression, reaching downward to the same source.[2] Soon after this, at the end of October 1914, the lava emerged from these vents and began

[1] A. Malladra (4 and 6). [2] Washington and Day (1), p. 379.

filling the semicircular depression, thus starting a second phase of the new eruptive period. The rising lava soon formed an eruptive conelet (Fig. 73), and from this time onward, up to the date of writing (1921), the entire course of events in the external activity of this volcano has been characterized by an almost continuous process of crater-filling activity (Fig. 61), through superposition of material erupted explosively and effusively from the eruptive conelet and adventitious vents.

The simple mode of this upgrowth—i. e., cone-building through fragmental ejection and lateral flooding through overflow or breaking through of the walls of the cone— was naturally subject to many variations in detail, and as the present writer studied the outbreak of Sakurashima in 1914 and the lava eruption of Stromboli in 1915, not all of this earlier period of crater-filling activity came under his personal observation.

Fig. 78.—View of crater-floor on August 4, 1916, seen from midway of descent. The conelet is emitting only white vapors.

At the beginning of 1916 the activity within the crater assumed such proportions that the writer determined to investigate its phenomena at close range. On January 2, after several days of unusual quiet, the crater showed a very considerable explosive activity, with rapidly rising volutes of vapor, and at night a brilliant glare was reflected from what was evidently an exceedingly copious emission of fresh lava. This outflow from the base of the eruptive conelet covered a large portion of the crater-floor with material so liquid as to form as flat a type of pahoehoe as the writer has ever seen. The volume of the emitted material has been estimated at 2,000,000 cubic meters[1] and, as we shall see later, lakes were formed in certain areas, followed by outbreak and drainage to new levels (Fig. 82).

On July 30 a second outflow of at least half this volume occurred, and on August 4, 1916, taking advantage of favorable luni-solar conditions, the writer,

[1] Cf. A. Malladra (10), p. 143.

in company with Dr. Malladra and two guides, made his first descent into the crater, remaining 24 hours in order to make observations by night as well as by day.[1] The descent (Fig. 77) was begun down the south-southeast wall from a point on the crater-rim at 1,172 meters altitude and was continued by skirting the southern incline, past a point about midway of the descent, where good views were had of the crater-floor and active cone (Fig. 78). Thence was reached the head of the great southwest talus conoid by whose slope the bottom was attained.

Near the head of this conoid the "yellow fumarole" first claimed attention. Fairly complete data regarding this, the largest and most important of the channel-vents, have already been given (p. 110). It consisted of a number of openings on the lines of a fracture or series of fissures in the west-southwest wall, and its activity had been considerably diminished by the free opening of the main conduit and by the vicissitudes of its own various ramifications as results of the great

Fig. 79.—Detail of pahoehoe lava on crater-floor.

southwest landslide. The exhalations were very acid and included hydrogen fluoride in considerable amount, as was shown by the corrosion of the writer's camera lens, as well as by the etching of glass collecting-tubes. But they scarcely constituted at this time a perilous feature of the descent into the crater. Measurements of temperature gave 286°[2] at the principal opening accessible from the crater-floor (southwest talus conoid), whose altitude at this point was 947 meters above sea-level.

[For convenience in locating the various points mentioned in Perret's description of the crater-floor there is given in Fig. 62 (p. 101) a map, based on one of the many published by Malladra, of the crater-floor on December 31, 1920.[3] See also Fig. 61 (p. 100). H. S. W.]

The main floor of the crater, averaging 400 meters in diameter, was formed by the lava of January 2, which had been emitted in exceedingly liquid condition and had cooled, for the most part, to a remarkably flat surface, occasionally showing flow-terminals of lobes, pillows, and other grotesque formations characteristic

[1] Ibid., p. 143. [2] Thus in Perret's MS., but this differs from his statement on p. 110. [3] Malladra (14), Plate 2.

of the pahoehoe type (Figs. 79 and 80). Over the greater part of this smooth floor the rougher outflow of July 30 was superposed, which had a temperature of about 700° (A, Plate 24). There were deposits of ammonium chloride.

The eruptive cone, 60 meters high, contained lava in a state of continuous effervescence, with the characteristic metallic clanging sounds, and the upward and outward projection of incandescent blobs of lava and nearly horizontal spray whenever the lava rose almost level with the aperture (Plate 21, B). The ejected material corresponded in character to these conditions, being so charged with gas as to form shapeless vesicular masses that cooled to vitreous scoriæ with an irides-

Fig. 80.—An "icicle" of pahoehoe lava on crater-floor.

Fig. 81.—Near view of crater of eruptive conelet, from (x) of Plate 21, C.

cent luster, often acquiring later a coating of yellow-green salts. The conditions were essentially similar to those at Teneriffe in 1909 and at Etna in 1910, except for the frequent formation of lava threads, short and scarcely meriting the appellation of "Pele's hair." The high gas-content and great liquidity of the lava rendered the ejection of compact bombs exceedingly rare. Loose crystals of augite were fairly plentiful.[1] (Plate 21).

Pyrometric measurements of lava fragments, as they fell, gave temperatures ranging from 440° in the already cooled, smaller scoriæ, and up to 980° in very liquid masses, possibly 40 kilograms in weight. The writer collected a number of these incandescent fragments in sealed tins for laboratory examination.

[1] H. S. Washington and H. E. Merwin, *Note on augite from Vesuvius and Etna*, Am. Jour. Sci., *1*, 20, 1921.

The lowest level of the crater-floor at this date was at the base of the north-northeast wall, where the altitude was 927 meters. West of this point there was clear evidence of former temporary formation of lakes in the lava of January 2, with subsequent drainage and eastward flow to lower levels (Fig. 82).

The eruptive conelet exhibited, from one side, the classic "Monte Somma" formation partly inclosed by a remnant of the larger cone of an earlier and greater explosive activity. In a quiet interval it was possible to ascend this lateral peak (Plate 21, c) and obtain a near photograph (Fig. 81) of the active summit, whose altitude was 1,010 meters. The emitted gases were strongly acid with both hydrogen chloride and sulphur dioxide. On January 3, between the base of the eruptive

Fig. 82.—Remains of a drained lava lake on crater-floor.

conelet and the wall, explosions had formed a conical depression, now 45 meters in depth, and this foreshadowed the eventual rise of new lava at this spot.

Our bivouac was upon an eminence on the lava of January 2, about 80 meters from the eruptive cone. A considerable increase of activity occurred at midnight, shown by magnificent sheaves of luminous fragments, some of which were thrown as far as the main crater-walls and with, at times, a crater-glow sufficient to render visible the number of one's Kodak film (Fig. 83).

The crater-wall was reascended on the morning of August 5, the tubes of gas and liquid from the "yellow fumarole" being taken up in passing.

In the last 10 days of September the expected lava extrusion began within the conical depression of January 3, with the formation of the usual conelet. This became, in its turn, the source of outpourings of lava which, with the upward growth and the subsequent opening of the cone (the formation of which was more rapid than that of the first), resulted in the double-cratered cone photographed during the writer's descent in 1918 and reproduced in Fig. 84.

In 1917 the conduit lava acquired such a high temperature that the energy of its subsurface ramifications not only effected, in places, a partial fusion of

Details of northeast inner crater-wall, showing floor-level on August 2, 1917.

overlying material with consequent tumefaction and temporary exhaustion of effort in the erection of "schollendome" (Fig. 85), but often resulted in complete local re-fusion of the surface layers with upwelling of liquid lava, flooding the

Fig. 83.—Crater-glow and incandescent projections from eruptive conelet; taken at midnight, August 4, 1916.

neighboring areas. Malladra has termed these little eccentric sources "zampille," i. e., "little jets."

Fig. 84.—Detail of the crater-floor in August 1917. An eruptive conelet that had formed over the conical depression observed in the descent of August 4, 1916.

In February 1917 moderately powerful explosions reduced the height and enlarged the base of the principal eruptive conelet, its northern flank being fissured and its base ruptured, both openings giving rise to copious outpourings of lava.

The general increase of activity also extended to the above-mentioned second conelet erected over the former depressions in the southwest talus conoid. The mode of action of this conelet continued to be mainly of the violently explosive type, increasing to the extent of finally blowing off its top.

There followed many variations in the different forms of activity within the crater with rebuilding of the main conelet and with a number of large emissions of lava, which first surrounded the eminence of our bivouac of 1916 and finally overflowed and buried it out of sight. Details of this activity have been published by Malladra.[1] Malladra noted heavy rhythmic beats with intervals of 0.5 to 1 second. Compare the present writer's observation of the mountain's vibration during the culmination of the eruption with a period of 0.6 second (p. 82).

In its turn, this period of lava extrusion and explosive phenomena inside the crater was followed by three months of comparative inactivity, during which time not only was no lava emitted, but the crater-glow itself was generally absent.

Fig. 85.—A typical intumescence of lava ("Schollendom") on crater-floor, August 1917.

The causes of this general condition of pause are obscure. Malladra thinks that lowering of the magma column and partial obstruction of the conduit are mainly responsible. He cites in favor of this view an increase of seismic and subterranean acoustic effects and the appearance of fumaroles on the outer slopes of the mountain with exhalation of "mofetti" farther down.

We naturally know less regarding the causes of temporary passivity than of those of active external manifestation, as the former are more difficult of interpretation through their effects. A cooling mass of intruded magma, such as one that has no effect in producing volcanic eruption, will often give rise to seismic and acoustic effects that may be easily mistaken for signs of increasing activity.

[1] A. Malladra, *Sopra l'attività del Vesuvio nell'Aprile 1917*, Boll. Soc. Naturalisti Napoli, *31*, 37, 1917; *Riassunto sull'attività del Vesuvio per l'anno 1917*, *32*, 132, 1918.

A.—On the crater floor, August 4, 1916. In the immediate foreground is the flow of January 1916; above it the rougher lava of July 30. The eruptive conelet is 60 meters high.

B.—Summit of the eruptive conelet continuously ejecting liquid masses.

C.—View of eruptive conelet, showing "Monte Somma" ring.

The carbon-dioxide exhalation of "mofetti" is generally associated with the final stages of volcanic activity, although its usual appearance at the end of an eruption may be due to the obstruction of the main conduit and consequent increase of subterranean gas-pressure. This obscure subject of the intercommunication of gas-channels and the distribution of pressure throughout the internal passages of a volcano is in need of much further study.

It would be easy to imagine a number of factors that may have contributed to the maintenance of this condition of external calm, and these might even include a lowering of the temperature of the magma through failure in the supply of heat-bearing gas or by the engulfment of cold collapsed material. Inasmuch as the intrinsic activity of lava is so directly dependent on its temperature, the importance of this factor should not be ignored. The mere chilling of a lava column constitutes in itself an obstruction.

But neither this nor any other attempt at explanation is in full accord with the condition of the lava observed during our descent into the crater on August 2, 1917. At this time the lava, level was temporarily only a little below the orifice of the conelet's crater and the lava was seen to be in a condition of extreme liquidity and at a high temperature, with effervescence and gas-evolution sufficiently powerful to produce the usual throwing upward of liquid masses. These conditions certainly indicated neither obstruction nor serious diminution of potential activity. As most nearly consonant with the observed characteristics of this comparatively inactive period, the writer inclines to the hypothesis of a temporary and partial deviation of the magma in the conduit, through lateral injection, with an abortive attempt to form an eccentric vent; hence follow seismic and acoustic effects, development of fumaroles, and temporary abstraction of energy from the main channel. With the failure of the attempt to reach the surface, the ramifications would gradually cool to a condition of inactivity and the eruptive energies would be shunted again into the central conduit, restoring normally active conditions.

This restoration, however, can hardly be said to have really begun before the middle of September 1917, and in the meantime a peculiarly favorable luni-solar opposition, with coincidence of perigee and nearly equal north-south declinations, occurred on August 2 to 3. This date, therefore, was set for another 24-hour stay within the crater, and at 7 a. m. of August 2, 1917, the "yellow fumarole" was reached and its temperature found to be only 220°. The summit of the principal eruptive conelet, although changed to the pointed profile shown in Fig. 86, was actually 1 meter less high than a year ago (1,009 meters above sea-level).

The crater of the little cone was divided into three openings, its one gulf being domed and bridged across by the lava splashes of an exceedingly moderate and purely constructive form of "Strombolian" activity. The three vents gave perfectly simultaneous puffings of vapor, one toward the southeast projecting almost horizontally; and the effervescence of lava within the crater was effected quietly, but with copious outpouring of vapor, indicating a high temperature and great liquidity of the lava. This was further demonstrated when (evidently in response

to the peculiarly powerful luni-solar influence) the activity steadily increased throughout the day of August 3 and culminated in very considerable projections of liquid masses for the first time during this period of comparative repose. The eruptive conelet itself, instead of growing, as usual, by the superposition of ejected liquid drops, had become coated with a layer of green salts.

The continued rising of the crater-floor (by superposition of erupted materials) had now become especially interesting. It had reached a level where, upon the northern wall of the crater, a number of dikes and sills formed a convenient scale (Plate 20) by which photographically to record the degree of crater-filling at differ-

Fig. 86.—Pointed eruptive conelet of August 1917.

Fig. 87.—Eruptive conelet on August 26, 1918.

ent dates. Fig. 88 shows the lava-floor at the level of a short, thick horizontal dike left exposed on the north wall of the crater at an altitude of 932 meters. In Fig. 59, showing the crater in 1909, this dike can be seen near the center of the picture. The lava had now filled the old cylindrical central well, above whose upper edge the crater-walls slope outward, so that from this time onward the diameters of the successive crater-floors increase and more material is needed for each added meter of elevation.

On August 3 a reduction of the activity of the conelet was evident, the vapors on rising through the crater-vents being first expelled and then strongly sucked in by a subsidence of the interior lava after the emission of each puff of gas. The increased activity of the preceding day was thus temporary and due undoubtedly to the luni-solar influence.

A, floor of crater, August 1918—an aa lava flow from the eruptive conelet that has sunk itself below the surrounding level; B, part of flow of A, in greater detail; C, a near view of eruptive conelet, August 26, 1918.

Increased activity was noticeable in the autumn of 1917, culminating in November with the rather rare occurrence of actual overflow of lava from the terminal crater of the eruptive conelet. This was followed in December by lateral outflows of lava from its base, which buried out of sight the horizontal dike in the northern wall, of which a photograph is given in Fig. 88.

The year 1917 ended thus with active conditions and the high temperature and abundance of gas were shown by renewed production of the stunted wisps of Pele's hair.

Nothing of extraordinary interest marked the first half of 1918,[1] and from June to August 23 there was a repetition of the quiet period of a year before, in a coincidence sufficiently marked to invite consideration, at least, of the hypothesis of their connection with the annual season of drought.

Fig. 88.—Crater floor (August 1917) at level of a sill in north wall, which can be seen also at about center of Fig. 59.

Another favorable luni-solar opposition occurred on August 22, 1918, with perigee near midnight of the 23d, and at 4 a. m. of the 24th the lava poured into the crater with a strong emission of vapor, forming a very considerable crater-cloud by day and a brilliant and continuous orange-red glow in the evening, with flashings of yellow light plainly visible from Naples.

On August 26, 1918, the writer, again with Dr. Malladra,[2] descended into the crater. The principal conelet was higher and even more pointed (Fig. 87) than it was a year before, with strong effervescence in the liquid which filled the cavity almost to the brim. There was occasional ejection of liquid fragments, but more especially a powerful and very continuous belching upward of vapor densely charged with incandescent particles, forming a uniform, redly glowing mass, in the midst of which there shot upward long, flashing tongues of yellow flame.

[1] For conditions during 1918, see Malladra (13).

[2] Malladra (13), p. 71.

The second vent, which began as a "funnel" in 1916 and became a lava dome in 1917, formed now an explosively active conelet with two incandescent vents puffing and emitting sharp reports like pistol-shots, strongly echoing from the

Fig. 89.—Second eruptive conelet, August 1918. (Cf. Fig. 84.)

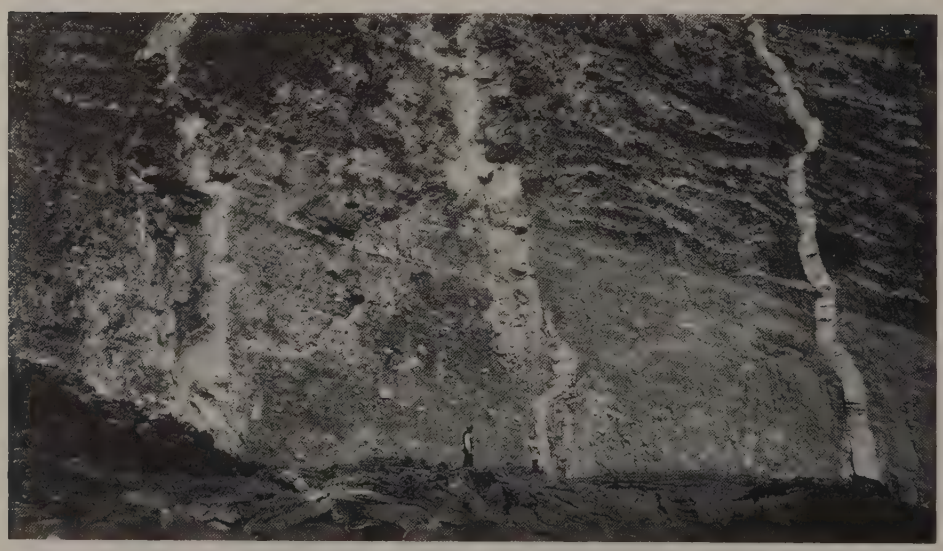

Fig. 90.—The level of crater-floor on August 26, 1918, at the "three dikes." (Cf. Figs. 61 and 88.)

crater-walls. A third vent had formed a driblet-cone in a higher conical structure adjoining the conelet on its west side (Fig. 89). Independent in action, this vent exploded strongly at intervals, scattering a few scarcely visible solid particles, its powerful, sudden discharges often tapering off in a long, whistling roar.

Summit of active eruptive conelet on the crater-floor, showing construction by cementation of semi-liquid masses.

The altitude of the summit of the main conelet was 1,047 meters above sea-level, that of the second was 1,036 meters, and the saddle between the two (now shifted to the westward) was 1,008 meters, all showing increased altitude as a result of the year's activity.

Fig. 91.—Pahoehoe lava-flows on crater-floor, August 26, 1918.

Fig. 92.—A "voccolillo," vent emitting gas at 560°, on crater-floor, August 26, 1918.

The lowest portion of the crater-floor, still at the north-northeast, was now 960 meters above sea-level, and at an adjacent point, where three dikes (Fig. 90) formed a convenient scale of reference, the altitude was 969 meters.

The general conditions at the crater-bottom were those of a much higher degree of activity than at the time of either of the former visits, with flowing streams of incandescent pahoehoe (Fig. 91), whose temperatures are given in table 2 (page 111), and an interesting gas-vent—"voccolillo" (little mouth) of the guides—emitting invisible vapor at a temperature of 560° C (Fig. 92).

The fluent lava issued from a source in the western sector of the crater-floor and was a remnant of the greater outpouring of the preceding day. Its flow was variable but always slow; the temperature ranged (Fig. 94) from 1,015° to 1,040° C.

A previous outflow of aa from the conelet's base had a temperature sufficiently high to fuse its bed and sink itself below the surrounding level (Plate 22A and B). Near views of the conelet emerging above lava fields are shown in Plates 21 and 23C.

Fig. 93.—General view of interior of crater on September 11, 1920. In the center is the eruptive conelet; at its base the mound of a lava outflow; to the left, in the background, are secondary conelets.

The subsequent course of activity at Vesuvius has consisted of repetitions of the crater-filling processes already described and the detailed enumeration or description of which would not be useful. The great crater has by these means become filled to about two-thirds of its former depth and to more than one-half of its cubic capacity (Fig. 93), and we may confidently predict a long continuance of these processes and the gradual filling up of the crater. The active vents will thus become increasingly accessible and will offer a rich field for direct observation and research. Degradational processes, on the other hand, are at work on the outer parts of the cone, so that much of the enormous amounts of material ejected by the eruption of 1906 has already disappeared (Plate 24).

Erosion of ash in 1906 in the Valle dell'Inferno. The wall of Monte Somma in the background. Photograph by A. L. Day, June 1914.

PART V. APPENDICES.

1. INSTRUMENTS AND EQUIPMENT

Photography.[1]—For photographing volcanic phenomena the writer's experience during the eruption of 1906, with its gas-filled and ash-laden atmosphere and other difficult conditions, was conclusively in favor of the roll-film camera, because of its portability, its simplicity of action, and, above all, the tight closing of the film chamber. The withdrawal of the slide of a plate-holder invariably admits ash under such conditions.

The folding pocket Kodak, size *3a*, is especially advantageous because of the form of the picture; if used horizontally the picture is almost panoramic, and if used vertically it will include a tall crater, cloud. The writer has advocated the general adoption of this type of camera on account of the advantages of having pictures of the same size and shape, even though taken by different observers, and of using an interchangeable size of roll. Nearly all Italian volcanologists now employ this size.

An anastigmatic lens is, on the whole, the most desirable because of its flat field and covering power, and especially because it works at full opening. The actinic rays

Fig. 94.—Electric pyrometer measurement of temperature of slow-moving lava on crater-floor, August 26, 1918.

are very much absorbed in an atmosphere laden with dust, and the rapid motion in nearly all forms of volcanic activity makes very brief exposure necessary. The only disadvantage that this type of lens presents in volcano work with a film-camera having a focusing scale is the necessity of accurately measuring or estimating the distance when photographing near-by objects, whereas a lens of the ordinary rapid rectilinear type has greater depth of focus but with less sharp definition at any point.

The great latitude in length of exposure possessed by the modern film is of the greatest advantage, especially in night work, but a more autochromatic emulsion is becoming increasingly necessary for the study of volcanoes.

[1] Tempest Anderson (*Volcanic studies in many lands*, London, 1903, p. xxiii), who also has had wide experience in volcanic photography, makes suggestions regarding cameras and lenses for volcanic work. (H. S. W.)

Stereoscopic photography is valuable for the after-study of the subjects and the modern small outfits of the "Verascope" type are most satisfactory, except, perhaps, for subsequent reproduction as illustrations. Many special applications of cinematography are obviously indicated and the writer has done some work of this sort. Ultra-rapid apparatus would be valuable in analyzing explosive phenomena.

Temperature measurement.—For the measurement of temperatures the writer has introduced into Italy, as a standard instrument for field-work, the thermoelectric pyrometer of the Bristol type. The galvanometer is provided with two scales, one from 0° to 440° and the other from 0° to 1400°, with a calibrating screw. The fire-end is at least one meter long, attachable by thumb-screws to a second rigid piece connected with several meters of flexible insulated cable, in good contact with which there should be mounted a small thermometer for reading the cold-end temperature. The instrument may be calibrated to a cold-end temperature of 20° to 25°, and any variation from this, as read on the small attached thermometer, is added to or deducted from the galvanometer readings. The great length of the fire-end makes it very convenient for introducing into hot fumaroles and, if bound to a pole, for reaching incandescent lava.

Final decision as to the superiority of the thermoelectric pyrometer was not reached until after long and arduous experiment with other forms. Aside from the crudeness of the older method of melting wires of different metals, its indications were found at Kilauea, in 1911,[1] to be without value, as iron fused easily at 1050° because of the presence of sulphur in the lava, showing that the fusion of metal wires under such conditions may be, not a purely thermal, but a thermochemical process. Seger cones have been used with success by Jaggar at Kilauea.[2] Pyrometric apparatus consisting of a platinum resistance with connecting cables, battery, and galvanometer was found to be impracticable because of its fragility.

Optical pyrometry is ideal only on the rare occasion of a sufficient area of incandescent lava, as within a small inclosed crater or under the roof of a "spatter grotto." Exposure to aerial radiation immediately forms a surface film by congelation, and the hotter the lava the steeper will be the temperature gradient, with correspondingly rapid loss of heat. It is truly surprising to see, at Kilauea, a dark skin forming on a fountain dome of the hottest lava in the very act of ebullition.[3] The temperature of the Kilauea lava lake was finally measured by means of a thermoelectric junction with water-jacketed cold-end and was found to be 1050°.[4] Since that time the writer has used the portable Bristol type of pyrometer exclusively, and ten years of active work in the field prove it to be the least liable to injury and the most practical for general use. Italian stations and private observers are now equipped with instruments of this type. Recording pyrometers might be exceedingly useful at outpost stations.

Collection of gas.—Collection in vacuum tubes is now the accepted method of bringing volcano gas to the laboratory for analysis, and most of the recent specimens have been obtained in this way. At the Solfatara of Pozzuoli the writer was able to utilize the natural pressure at a branch of the Bocca Grande in forcing the gas through a series of collecting bottles with a water valve at the farther end. The size of the opening at the Vesuvian external fumarole A (Fig. 67) precluded its being closed, so that an aspirating pump had to be used, although the gas pressure was high. This method was also used by Day and Shepherd at Kilauea.[5] At the yellow fumarole some collections of gas were made by means of its own pressure.

[1] Day, A. L., and E. S. Shepherd, *Water and volcanic activity*, Bull. Geol. Soc. Amer., *24*, 588, 1913; Perret, *Volcanic research at Kilauea in the summer of 1911;* Am. Jour. Sci., *36*, 478, 1913.

[2] Jaggar, T. A., *Volcanological investigations at Kilauea;* Am. Jour. Sci., *44*, 208, 1917.

[3] Perret, *The lava fountains at Kilauea;* Am. Jour. Sci., *35*, 139, 1913.

[4] Perret, *Volcanic research at Kilauea in the summer of 1911;* Am. Jour. Sci., *36*, p. 479, 1913.

[5] Day and Shepherd, *Water and volcanic activity;* Bull. Geol. Soc. Amer., *24*, 581, 1913.

Because of the great difficulty in obtaining unoxidized gas in the usual ways, the writer has attempted to entrap the gas inclosed in expanding vesicular bombs and other masses ejected from the effervescing lava. This was done by placing the still liquid material in hermetically sealed tins, or by coating very vesicular, recently fallen bombs with a solution of rubber to fill up the finer pores and then by a thick layer of wax. These might be expected to yield some gaseous material of value, if opened under mercury in the laboratory (p. 123).

Qualitative analysis of gas.—A qualitative determination of gases in the field is often advisable. The sensitiveness of the nose, if trained to distinguish slight differences, is often sufficient, except when several gases are present. The specific odors of hydrogen chloride, sulphur dioxide, and hydrogen sulphide are marked. The rarer, but actively corrosive, sulphur trioxide was thus detected by the writer at Kilauea and the determination was confirmed by a snow-fall of flocculent zinc sulphate from the galvanized iron roof of the writer's hut.

Reaction of ammonia to hydrogen chloride is a simple test, but one that is inconclusive in a strong wind; the exposure of solution of silver nitrate, acidified with nitric acid, on a glass rod is preferable. Lead acetate solution serves as a reagent for hydrogen sulphide and lime water for carbon dioxide. For the detection of sulphur dioxide a reagent, suggested by Casoria,[1] may be used. This consists of a precipitate formed by mixing solutions of 3 parts of sodium nitroprusside and of 5 parts of fused zinc chloride and adding a solution of 3 or 4 parts of potassium ferrocyanide. The yellow precipitate is spread on filter paper and, if moistened with ammonia water, will turn to a reddish purple on exposure to sulphur dioxide.[2] The reagent is not affected by hydrochloric or hydrofluoric acids.

Seismographs.—The study of seismic movements is of the greatest importance in volcanology and a standard portable seismograph is becoming essential in the equipment of the student of volcanoes.

For the detection of microseismic movements and the measurement of the velocity of transmission of tremors caused by explosions a surface of mercury answers well, so that a small saucer and a bottle of mercury are desirable in a field equipment.

The writer has often succeeded in obtaining valuable results with the crudest of apparatus improvised out of such materials as could be found on the spot. At Teneriffe, in 1909, the eruption was followed by a series of sudden, sharp shocks accompanied by sound. The inhabitants of Icod, the nearest town, influenced by a local legend, according to which the Peak itself must one day burst into eruption, were very apprehensive; so that it was important to determine if the site of the recent eruption or the central axis of the volcano was the source of the activity, the two directions, fortunately, forming an angle of 60° with Icod.

A mass of lava was suspended from a roof beam by a strong cord, which, after a time, untwisted to the extent of about one revolution per day. Upon the under side of the lava block there was mounted eccentrically a needle that slid vertically in a bent frame. The point of the needle thus traced a circle upon an underlying sheet of smoked paper. This simple apparatus registered three shocks, with unquestionable indications that the site of the eruption was the point of origin.

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[1] Cf. Perret (1), p. 419.

[2] This is an application of a long-known method for the detection of sulphites in solution. See Fresenius, Qualitative Chemical Analysis, 17th ed., New York, p. 402; Treadwell, Qualitative Analysis, 4th ed., New York, 1916, p. 349. Dr. E. G. Zies, of the Geophysical Laboratory, who has investigated the reagent in the detection of sulphur dioxide gas, informs me that the reagent is sensitive only when freshly precipitated, which is probably the reason that I found it unsatisfactory at Vesuvius, Etna, and Stromboli in 1914. Dr. Zies also says that it is affected by hydrogen sulphide only if this is very concentrated, in which case a slight pink color appears. He suggests the addition of zinc oxide to obviate the necessity of moistening with ammonia water. (H. S. W.)

At Etna, in 1910, a mass of iron, found at the writer's headquarters at the Cantoniera, 160 meters from the eruptive center, was suspended as a pendulum, interlocking with an extremely light lever that gave an amplification of 30 to 40. The tremors of this pointer gave a sure indication in advance of each explosive crisis.

The Vesuvian Observatory, in 1906, was equipped with what would now be called very crude seismographic instruments. These were, nevertheless, surprisingly effective during the great eruption, the heavy earth-tremors of which would have thrown an ordinary modern seismograph out of action. Four simple pendulums, 42, 92, 192, and 392 centimeters long, were suspended from a wooden wall-post. They terminated in vertically sliding needles the points of which rested lightly upon horizontal glass disks strewn with lycopodium powder. There was also a Cancani seismoscope consisting of seven inverted and spring-supported pendulums of from 1.4 to 14 centimeters effective length, with extensions terminating in sensitive spirals of fine wire, whose quivering amplified the movement of their weights. The chief value of these two forms of appa-

95

96

Fig. 95.—Simple type of microphone; useful in solfataric conditions.
Fig. 96.—Portable microphone for simple ground contact.

ratus, aside from their robustness, which permitted them to function continuously, lay in the multipendular construction with consequently different periods, that permitted independent selective synchronism with the seismic vibrations, thus aiding in the determination of the fundamental vibration period of the volcano.

An Agamennone bi-pendulum with far and near fulcra, designed to respond to any length of wave, was most useful to the writer. It interlocked in an electric circuit so as to record, by a totalizing meter, the number of earth tremors received. Although it was too sensitive for the culminating activity, and although the recording device was rendered superfluous by the multiplicity of shocks, this instrument was valuable during the third period for studying, through the propagation of explosion tremors, the direction of the main seismic throw at the volcano (p. 83).

Microphones.—The microphone is, in the writer's opinion, second only to the seismograph for the instrumental study of volcanism, and it is time that the former prejudice against this kind of instrument was removed. This was due, at first, to its having been tried with scant success in the study of earthquakes—surely not a valid argument against

its employment in the study of volcanoes, where sound phenomena constitute an elemental characteristic. The prejudice was also fostered by faulty construction and the use of types of instrument that were not well adapted to the peculiar methods of mounting demanded by the conditions.

Milne, for example, states:[1] "Cancani found that as much sound could be heard in the telephone connected with the microphone resting upon a bed of cotton wool as in one connected with a similar instrument installed upon rock, while the writer found very marked difference in the indications of two such sets of apparatus arranged side by side." Jaggar has written from Hawaii to the writer to the same effect. But, aside from the fact that cotton wool is a fair conductor of sound, any microphone circuit that is not absolutely silent when there is no molecular vibration is faulty in construction or installation, if the current is not variable.

Fig. 97.—View from summit of Vesuvius looking down western flank; in the foreground the ash-covered lava cupola of 1895 (Colle Umberto I); beyond are the western end of the Monte Somma ridge and the small triangular "dagala" on which is situated the Vesuvian Observatory.

Until such time, however, as some standard apparatus specially adapted to this line of research is available, the volcanologist will obtain but poor results, unless he himself is a practical expert in microphone construction. The writer had no lasting satisfaction until he began to build his own apparatus. The general neglect of the microphone in volcanic research is but another demonstration that in this many-sided branch of science there are approaches still awaiting development.

Subterranean acoustic vibrations may be brought to the sensitive element of a microphone either through a closed column of air or by direct solid contact, the two methods requiring very different construction and installation.

The first type was used by the writer in an apparatus installed at the Volcanological Institute of Dr. I. Friedländer, on the Vomero at Naples. A demijohn was placed in an excavation in the volcanic tuff and was packed around with rock fragments, after which liquid cement was poured into the cavity, thus bringing the surface of the recep-

[1] J. Milne, *Seismology*, 1 ed., p. 73, 1898.

tacle into intimate connection with the surrounding rock. A metal tube through the stopper was extended upward into the instrument room, and terminated in an elbow that carried the microphone unit, whose sensitive diaphragm received the vibrations of the inclosed column of air. This apparatus, although not in connection with a volcanic center, gave satisfactory results in transmitting artificially produced subterranean sounds.

For field-work, practically the same principle has been used in the portable apparatus illustrated in Fig. 95. The writer prefers, however, as the result of much experience, the method of direct solid contact. In portable instruments a closed metallic case contains the microphone unit soldered to one of its faces, and the simple contact obtained by placing the box upon the ground, as shown in Fig. 96, is sufficient. With this apparatus the positions of three underground fractures radial to the Bocca Grande at the Solfatara of Pozzuoli were readily determined. The dimensions have been so reduced, in some of the instruments lately made, that the 4½-volt battery made for the flat pocket form of electric torch has been found to be satisfactory. In Japan and at

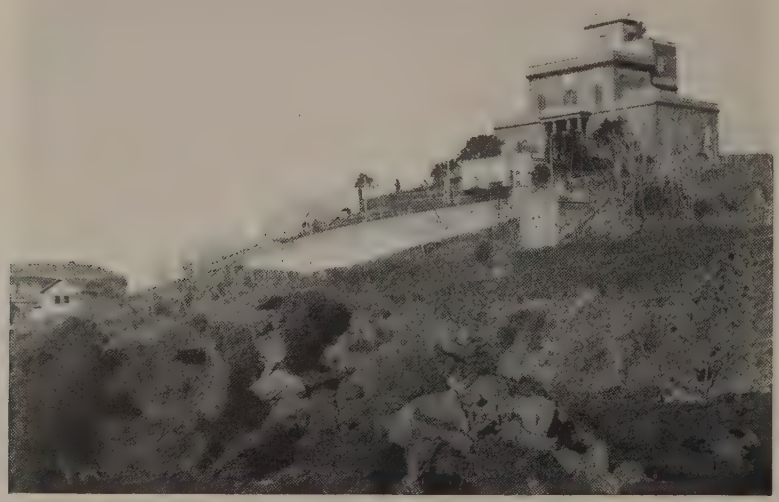

Fig. 98.—The Royal Vesuvian Observatory, seen from the lava of 1905. Hotel Eremo and the "chalet" at the left.

the Italian volcanoes the writer has obtained results of interest and value with this small adjunct to his field equipment.

Mercalli and Malladra installed a very simple instrument of the rock-contact type in a cave near the Observatory. This gave fair results, but the site of the Observatory, on the Monte Somma ring, and consequently not in intimate connection with the central Vesuvian edifice, is not advantageous. The electric microphone fortunately permits of installation at a distance from the observer, connection being made by wire, and the lava cupola of Colle Umberto I (Fig. 97) would probably constitute a foundation in good rock connection with the main Vesuvian shaft.

But the real value to volcanology of the collection and amplification of subterranean acoustic vibrations will not be fully realized until these can be recorded. The difference between the mere listening to these sounds and recording them in a graph is equal to that of watching the oscillations of a seismoscope and obtaining the permanent seismogram of an earthquake.

There are two methods of recording such sounds: incision upon a wax cylinder for audible phonographic reproduction, and the tracing of a permanent graph. Thanks to

the flexibility of the electric circuit, the use of one of these need not exclude that of the other. The writer's first efforts were devoted to the simpler problem of phonographic registration upon wax by including in the microphone circuit an electromagnetic engraving device. The recording experiments were carried out at the Pozzuoli Solfatara and later at the writer's studio in Naples. Mercalli did not hesitate to affirm that these Solfatara records convinced him of the existence in that conduit of the subterranean explosive emission of dry gas, with displacement of solid masses, instead of the ebullition of water.

But obviously the permanently visible graph is the ideal form of record, and, realizing this, the writer attempted to construct an experimental apparatus, although he had no illusions as to the difficulty of recording mechanically the very feeble vibrations that are sensed by the human ear. In the sound-collecting microphone, which was designed for maximum sensitiveness combined with large current capacity, the ability to reproduce articulate speech clearly was to some extent sacrified, as unnecessary, in favor of other qualities. In the electromagnetic receiving and recording mechanism the essential features were great amplification of the vibrations and maximum elimination of inertia in the moving parts. A multiplication of 600 was obtained by a double-leverage system, of which the second and most mobile unit was the shaft of the balance-wheel of a watch, with the wheel itself removed and the hairspring retained for tension. A silk fiber wound around the tiny axle and attached to the first lever effected partial reciprocal rotation, which a light pointer, made of thin sheet-celluloid, amplified still more in a tracing upon smoked paper mounted on a revolving drum. This formed a compact and small apparatus that was so practical and effective as to indicate the possibility of its use as a portable seismograph. Eventually, perhaps, the photographic method of recording by means of the movements of a beam of light may be found to be preferable.

The writer has not, as yet, tried a Rochelle-salt crystal as a collecting medium, but he does not hesitate to predict that the volcanic observatory of the future will record subterranean sounds as it now does the grosser seismic movements. This, with many another desideratum, awaits the day when volcanology is subsidized on a par with other sciences, and its instruments and equipment are standardized and made available by all.

2. DIAGRAMMATIC RECORD.[1]

The object of this diagrammatic method is to present all the various characteristics of a volcano's activity in their relative proportions, and thus to reveal, in a composite figure, the true character of the eruption at any given date, a series of diagrams constituting a record of the changing phases of volcanic activity during the course of an eruptive cycle. The diagram is intended to supplement the observer's notes and photographs, and to give a summary impression of what would otherwise be detached and fragmentary. This totalization, so to speak, of the eruptive phases and, at the same time, the revelation of their characters in detail, render the finished diagram at once synthetic and analytic. Because of the sensitiveness of the human eye to minute differences of form and angle, the diagrammatic figure gives an immediate and accurate impression of the manifested characteristics, and thus conveys to the mind a comprehensive view of the volcanic conditions that is unattainable by other means.

The diagram chart is in the form of a simple post-card; one side is spaced for the address and notes, and the other (see diagram 1) is devoted to the diagram proper, which is constructed as follows:

Eight radii diverge from a center and terminate in a correspondingly divided circle which, with its extensions, is the key of the diagram. The divisions of the circle are marked to represent the different classes of phenomena in their most general terms—

[1] F. A. Perret, *The diagrammatic representation of volcanic phenomena;* Am. Jour. Sci., *37*, 48, 1914.

explosive, effusive, seismic, etc.—and these are further subdivided in considerable detail as indicated by appropriate letters and numbers.

Each radius is a line of small blank circles which are to be blackened or filled in progressively from the center, according to the relative value that is assigned to the class of phenomena that the radius represents. Thus, if a given class of activity is absent none of the corresponding radial circles are filled in; whereas if the special form of activity is extreme all of its radial circles are to be filled, intermediate degrees of activity being indicated by the number of circles filled. Tie-lines are then to be drawn between the radii, intercepting these at the farthest filled circle, thus inclosing a space and making a figure the form and angles of which the eye readily appreciates. This type of radius

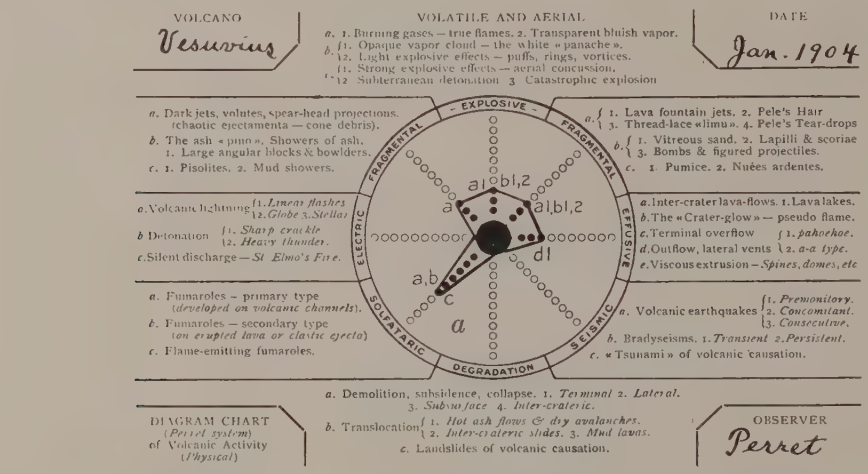
VOLCANO
Vesuvius
VOLATILE AND AERIAL
a. 1. Burning gases — true flames. 2. Transparent bluish vapor.
b. 1. Opaque vapor cloud — the white «panache».
2. Light explosive effects — puffs, rings, vortices.
1. Strong explosive effects — aerial concussion.
2 Subterranean detonation 3 Catastrophic explosion
DATE
Jan. 1904
a. Dark jets, volutes, spear-head projections. (chaotic ejectamenta — cone debris).
b. The ash «pumice». Showers of ash.
1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.
a. 1. Lava fountain jets. 2. Pele's Hair
3. Thread-lace «limu». 4. Pele's Tear-drops
b. 1. Vitreous sand. 2. Lapilli & scoriae
3. Bombs & figured projectiles.
c. 1. Pumice. 2. Nuées ardentes.
a. Volcanic lightning 1. Linear flashes 2. Globe 3. Stellar
b Detonation 1. Sharp crackle 2. Heavy thunder.
c. Silent discharge — St Elmo's Fire.
a. Inter-crater lava-flows. 1. Lava lakes.
b. The «Crater-glow» — pseudo flame.
c. Terminal overflow 1. pahoehoe.
d. Outflow, lateral vents 2. a-a type.
e. Viscous extrusion — Spines, domes, etc
a. Fumaroles — primary type (developed on volcanic channels).
b. Fumaroles — secondary type (on erupted lava or clastic ejecta)
c. Flame-emitting fumaroles.
a. Volcanic earthquakes 1. Premonitory. 2. Concomitant. 3. Consecutive.
b. Bradyseisms. 1. Transient 2. Persistent.
c. «Tsunami» of volcanic causation.
EXPLOSIVE
FRAGMENTAL
EFFUSIVE
SEISMIC
DEGRADATION
SOLFATARIC
ELECTRIC
a1
bl,2
a
a1,bl,2
d1
a,b
c
a
a. Demolition, subsidence, collapse. 1. Terminal 2. Lateral. 3. Subsurface 4. Inter-crateric.
b. Translocation 1. Hot ash flows & dry avalanches. 2. Inter-crateric slides. 3. Mud lavas.
c. Landslides of volcanic causation.
DIAGRAM CHART
(Perret system)
of Volcanic Activity
(Physical)
OBSERVER
Perret
Dec. 1904
b
Mar. 1905
bl,2,3
c
1905
May 27
d2
a1,2
d

Diagram 1, *a–d*. Jan. 1904—May 27, 1905

has been adopted because it forms a convenient decimal scale of values, because it is easier to blacken a small circle than to draw a straight line of a definite length, and because the filled-up radius, which indicates the value assigned to the class of phenomenon, is very prominent. The particular detailed subdivision of any class of activity is to be indicated by its letter and number; if there is more than one the appropriate circle that indicates its value may be left blank, thus contrasting with the others and marking the value of that particular form of activity. A brief examination of the diagrams illustrated in diagrams 1, 2, 3 will render the method clear.

Inasmuch as the volcanic forces and manifestations are not measurable in exact terms, it is evident that these diagrams can not be mathematically precise. It is not intended to indicate, for example, the gas-pressure per square centimeter at any given

outbreak, nor to compare rigorously the various phases of an eruption at one volcano with those at another. The object is, rather, to present all the forms of activity of an eruptive phase and, by their relative proportions, to reveal its salient characters. When the maximum values have been once adjudicated it is not difficult to estimate the lesser values in relation to these. The first and second circles of a radius may be considered as the feeblest and most restricted activity; the third to fifth (inclusive) a moderately strong or extended activity; the sixth to eighth very powerful effects; whereas the ninth, and especially the tenth, are reserved for those extreme and catastrophic developments of energy in regard to which there never exists a doubt in the mind of the observer.

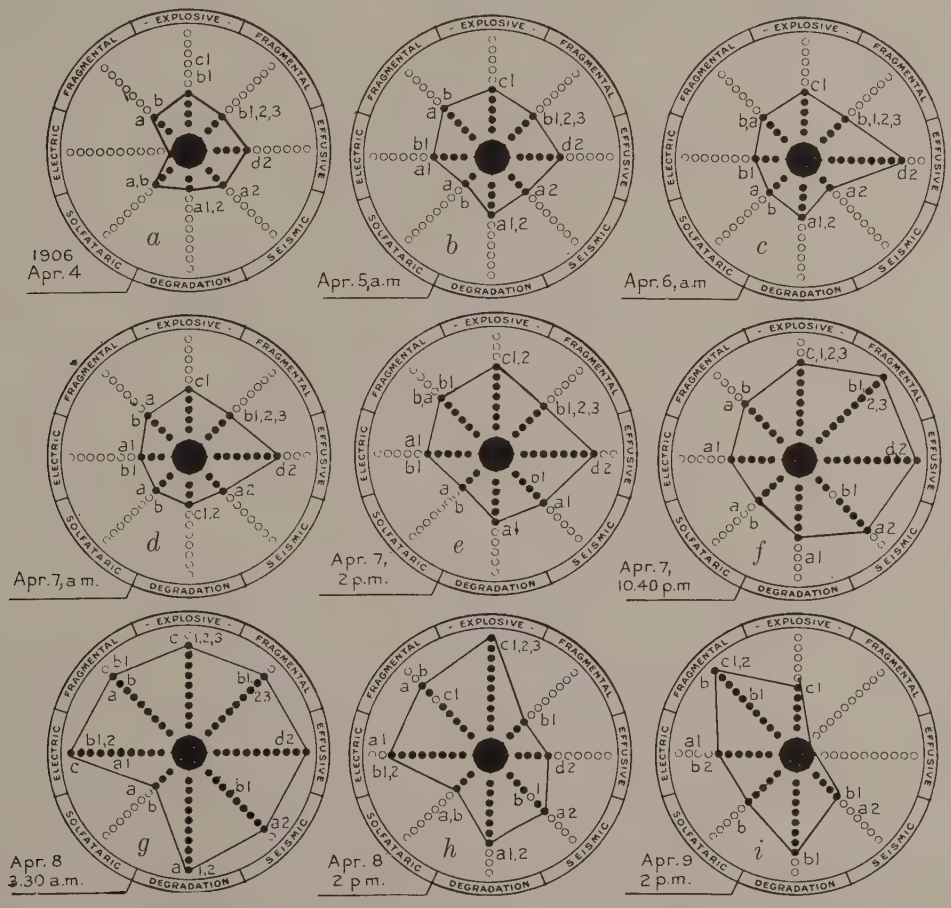

Diagram 2, *a–i*. April 4—April 9, 1906

The reader will note that the emplacement of the various forms of activity around the circle is in accord with the nature of the phenomena. Thus, the upwardly diverging radii represent the explosive forms of energy, the vertical being devoted to the gaseous products and phenomena directly dependent on them, with the fragmental ejecta adjacent on each side, lapilli on the right, ash and detritus on the left. The lowest vertical radius indicates degradation and deformation of the volcanic edifice by the general process of descent through gravity. The effusive line is horizontal on the right, while the corresponding left-hand radius represents electrical effects and is adjacent to the

radius that indicates ash and detritus which are essential to the development of electrical phenomena at volcanoes. Seismic phenomena are placed at the lower right and the solfataric or fumarolic form of activity is represented at the lower left.

The diagrams reproduced here are intended to give a concise conspectus of the development of the widely different forms of activity at Vesuvius during the years of

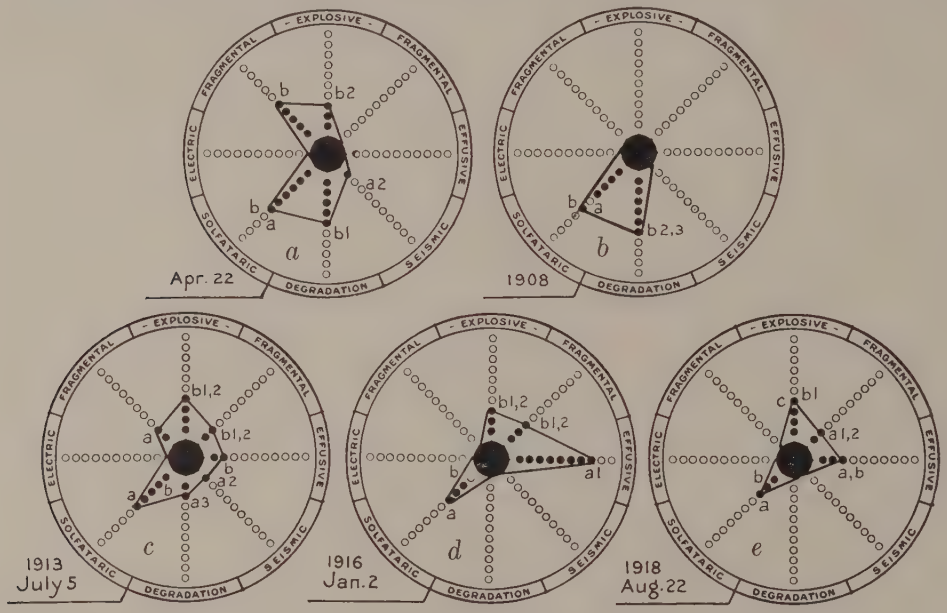

DIAGRAM 3, *a–e*. April 22, 1906—Aug. 22, 1918

observation that are comprised within this volume, that is to say, during the cycle of the 1906 eruption, the dates selected being those that reveal the principal conditions of which mention is made in the text.

NOTES

Dr. Perret gives here no further description of the diagrams that are illustrated (Diags. 1 to 3), and makes only a few casual references to them in the main text. It seems to the editor, however, that a brief description of them, calling attention to the main features of the successive phases of the cycle that they bring out, will be of interest and will illustrate their utility for purposes of the study of a volcanic eruptive cycle.

Diags. 1, *a*, *b*, *c*, and *d*, represent conditions during the years immediately preceding the culmination of the eruption, the "end of the pre-eruption period," as Perret calls it, or, what seems to me rather more appropriate, the first or introductory phase of the 1906 cycle. During this time the volcano displayed only very moderate activity, with only slight explosive action, an occasional moderate lateral lava-flow (Diag. 1*a* and *d*), and an apparently gradual diminution in fumarolic manifestations. No seismic tremors seem to have been recorded, and no electrical displays, probably because of the small amount of ash and other ejecta, as Perret says. There was little degradation of the cone; on the contrary, there was a continuous building up of the edifice brought about by the moderate ejection of fragments.

This condition continues up to April 4, 1906, when some seismic activity begins to be manifest. From this time on, for several days, all the elements of activity except the solfataric show a gradual increase in the diagrams, the rise in the value for the efflux

of lava being the first to become prominent. After and along with this the increase in the explosive and the lapilli ejecta phases becomes very prominent, the seismic and electric phases next increasing, until the culmination of the eruption, on the morning of April 8 (Diag. 2, *g*). Perret's luminous, liquid lava phase is represented by Diag. 2, *c*, *d*, *e*, the short but violent intermediate gas phase by Diag. 2, *f*, and *g*, in which the explosive activity reaches a maximum. In Diag. 2, *f* the ash and lapilli fragmental, the electric and the seismic forms of activity also reach maxima, the maximal degradational activity in Diag. 2, *f*, representing the boring out and enlargement of the throat by the mighty uprush of gas, as Perret has described so graphically. With Diag. 2 *h*, there comes marked diminution in the lapilli and seismic activities, the electric manifestations also falling off slightly. Here begins the third, dark ash phase, which is continued in Diag. 2, *i*, the last showing a great diminution in the explosive effects, but a maximum of ash and detrital ejection, while there are no longer either lapilli or lava-flows. By April 22 the volcano has settled down to almost moderate activity, with slight explosions, considerable ejection of ash, caused in large part by the internal degradation of the cone, and some increase in fumarolic action. The generally concomitant variation in the radii for electric and ash activities (Diags. 2*a*-3*a*) should be noted.

By 1908 the volcano has reached the lowest point of activity, the only evidences being numerous fumaroles, with many internal falls from the crater-walls that gradually fill up the throat and the lower parts of the crater bowl (Diag. 3, *b*). The year 1913 (Diag. 3, *c*, which is almost a replica of Diag. 1, *b*) brings us back to a state of affairs that closely resembles that represented by the diagrams for 1904 and 1905. Solfataric activity still keeps up, diminishing somewhat in the next few years (Diag. 3, *d* and *e*, but there is a resumption of explosive activity, with some ejection of lapilli and moderate flows of lava, which, however, are confined to the interior of the crater. It might be confidently predicted that within comparatively few years there will be a repetition of Diag. 2, *a* and *b*, and so on.

Attention may be called to a possible danger in the construction of such diagrams by inexperienced volcanologists, who may be apt to exaggerate or pay undue attention to some of the phases of activity and minimize or neglect others. In the case of those presented here, however, drawn, as they were, by a volcanologist of Perret's wide experience and remarkable powers of observation, they may be accepted as giving a very striking and instructive, although concise, idea of the general course of events during the Vesuvian cycle of 1906, and so, presumably, at other cycles of this volcano, and possibly at others. H. S. W.

3. COMPARATIVE DATA REGARDING THE ERUPTIONS OF 1872 AND 1906.

	1872	1906
Duration of eruption	4 days	18 days
Net loss in height of mountain as result of eruption	15 meters	107 meters
Depth of crater left by eruption	250 meters	700 meters
Cubic capacity of crater basin	17 million cubic meters	84 million cubic meters
Height to which materials were projected	6 kilometers	11 kilometers
Volume of solids ejected explosively	Not calculable, but far greater in 1906	
Volume of lava emitted fluently	Approx. equal amounts, about 20,000,000 cubic meters	
Repose period following eruption	3 years	7 years
Interval between eruptions (Average interval during 19th century was less than ten years.)	30 years	

The 1906 crater had, at the close of the eruption, a maximum diameter of 720 meters. This, by reason of downfalls of material, has considerably increased, and is now (1923) about 1000 meters. There results an area which receives over 600 tons of water for each millimeter of rainfall, producing, almost invariably, an increase of superficial activity after heavy rain.

The writer would call especial attention to the data given above, not merely because he believes the relative "greatness" of the 1906 eruption to have been generally overlooked, but because of the revealed tendency to an increased time-interval between eruptions, with consequent increase in the power of the eruption; for these two factors, in a volcano of this kind, are virtually reciprocal—longer periods give greater eruptions, and greater eruptions result in longer periods—and this modern tendency in the Vesuvian habit is of enormous significance in regard to the future. If continued—and all present indications point to its continuance—this means nothing less than a return to seventeenth century conditions, with all which that would imply.

4. PETROGRAPHY OF THE LAVAS OF 1906. (H. S. Washington.)

In order to render more complete Perret's conspectus of the Vesuvian eruption of 1906 there is added a short petrographical description of the lavas, based largely on specimens collected by me in 1914, 1918–19, and 1922. Such a description is the more desirable because there is reason to think that the various textural characters of the lavas, even though they may be practically identical in chemical composition, are closely connected with the type of the eruption, or with the particular phase of this during which the lava was erupted. The lavas themselves may thus serve to indicate something about the conditions in the conduit at the time of their emission, and therefore their petrographic characters form part of the documents that are available in studying the eruption that Perret has so graphically described and from which he has drawn such important conclusions as to its mechanism. This is a feature of volcanology for which we have very few data and which has been much neglected, but from the study of which it seems possible to obtain much knowledge as to the internal conditions, so that such facts as may be presented for the exceptionally favorable occasion of the eruption 1906 at Vesuvius may be not without value. Perret does not discuss this feature of the eruption, but Mercalli[1] has given his observations on the changes in the megascopical characters of the lavas at different periods, and some information may also be obtained from Lacroix.[2] It is hoped to take up this matter more fully in another publication. Zambonini[3] has written comprehensively on the minerals of Vesuvius.

The lavas of the central Vesuvian cone have been, since the eruption of 1631, remarkably uniform in their mineral and chemical composition.[4] Most of them, including all the lavas of 1906, are leucite tephrite, composed essentially of very calcic plagioclase (labradorite, bytownite, and anorthite), leucite, and augite,[5] with accessory magnetite and apatite, and in some specimens small and variable amounts of olivine and nephelite. The amount of olivine in some of the lavas is so great that the rock may be called leucite basanite, although there seems to be little constant difference in chemical composition.

Lacroix has shown, by numerous chemical analyses and microscopical descriptions, that many of the lavas of Somma differ widely from those of the central cone, and that they are, in general, much more sodic, indicating a radical change in the character of the magma since the great Plinian explosion of 79 A. D.

The general chemical uniformity of the Vesuvian lavas is shown by the following analyses, selected from the more trustworthy and recent among the very many analyses of these lavas that have been published:

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[1] G. Mercalli, *Notizie vesuviane*, Boll. Soc. Seism. Ital., *2*, p. 27, 1896; and Mem. Accad. Lincei, *24*, p. 23, 1906.

[2] A. Lacroix, Nouv. Arch. Museum, *9*, 22, 1907.

[3] F. Zambonini, *Minerologia vesuviana*, Mem. Atti. Acad. Sci. Napoli, *14*, No. 7, 1910, and Appendix, 1912.

[4] The literature on Vesuvian lavas is very extensive. Some of the more important papers are: C. W. C. Fuchs, Mineralogische und chemische Untersuchung der Vesuvlaven, Neu. Jahrb., 1866, p. 667, 1868, p. 552, 1869, pp. 42 and 168; S. Haughton and E. Hull, Report on the chemical, mineralogical, and microscopical characters of the lavas of Vesuvius from 1631 to 1868, Trans. R. Irish Acad., *26*, p. 49, 1876; A. Lacroix, Les produits laviques de la récente éruption du Vésuve, C. R. Acad. Sci., *143*, p. 13, 1906; Sur la constitution pétrographique du massif volcanique du Vésuve et de la Somma, C. R. Acad. Sci., *144*, p. 1245, 1907; Etude minéralogique des produits silicatés de l'éruption du Vésuve (Avril 1906), Nouv. Arch. Museum, *9*, 1907; H. S. Washington, The Roman comagmatic region, Carnegie Inst. Pub. No. 57, 1906.

[5] H. S. Washington and H. E. Merwin, *Note on augite from Vesuvius and Etna*, Am. Jour. Sci., *1*, p. 20, 1921.

It will be seen that, although there are slight differences here and there, the chemical composition of the Vesuvian lavas has not changed appreciably since 1631.

There are several main megascopic types of Vesuvian lava that, for the most part, are readily distinguishable from one another. In one the phenocrysts are practically all of leucite, in another of leucite and augite, in another of augite with scarcely any or none of leucite, while a fourth rather common textural type shows no phenocrysts or so few that they may be regarded as negligible. Olivine phenocrysts occur, generally with those of augite, less often with those of leucite, in some of the lavas. It is noteworthy that plagioclase rarely occurs as megascopic phenocrysts in Vesuvian lavas.

	1	2	3	4	5	6
SiO_2	47.71	47.65	48.10	47.50	48.28	47.30
Al_2O_3	17.61	18.13	17.56	18.59	18.39	16.81
Fe_2O_3	2.46	2.63	2.48	1.52	1.12	2.19
FeO	5.68	6.48	6.10	7.62	7.88	6.91
MgO	4.80	4.19	4.27	3.86	3.72	5.16
CaO	9.42	9.01	8.16	9.16	9.20	10.43
Na_2O	2.75	2.78	2.65	2.72	2.84	2.33
K_2O	7.64	7.47	7.93	7.05	7.25	6.86
H_2O+	trace	0.13	0.13	1.25	0.62	0.20
H_2O-	....	0.11	0.04			0.16
TiO_2	0.37	1.13	1.47	1.05	1.28	1.13
P_2O_5	0.77	0.50	1.01	n. d.	0.51	0.70
MnO	n. d.	n. d.	n. d.	n. d.	n. d.	0.09
	99.53	100.47	99.91	100.32	101.09	100.63

1. Lava of 1631, La Scala, Torre del Greco. Washington, analyst. H. S. Washington, Carnegie Inst. Wash. Pub. No. 57, p. 118, 1906. Includes ZrO_2 0.06, S none, BaO 0.26.
2. Lava of 1872, below Observatory. Washington, analyst. Op. cit., p. 104. Includes ZrO_2 0.02, BaO 0.24
3. Lava of 1903, Valle dell'Inferno. Washington, analyst. Op. cit., p. 116. Includes ZrO_2 trace, S none, BaO 0.08.
4. Lava of 1906, scoria of beginning of the eruption. Pisani, analyst. Lacroix, Nouv. Arch. Museum, *9*, p. 21, 1907.
5. Lava of 1906, end of Bosco di Cognoli flow at Torre Annunziata. Pisani, analyst. Lacroix, op., cit., p. 21.
6. Lava of 1914, fresh scoria from bottom of crater. Washington, analyst. U. S. Geol. Survey Prof. Paper 99, p. 691, 1917. Includes ZrO_2 none, Cl 0.06, S 0.07, BaO 0.23.

Mercalli pointed out that the "slow-moving" lavas, such as those of the eruption of 1872 and those from the subterminal vents in 1905, are of the type with numerous leucite phenocrysts, whereas the "rapidly-moving" lavas, as those of 1895 and of the Bosco di Cognoli flow, are rich in augite phenocrysts, with fewer of leucite. The specimens collected by me verify Mercalli's observations.

The lavas of the northwestern flows, of 1905 to April 1906, are shown, for example, in a specimen collected in June 1919 near the lower funicular station. This is dense, non-vesicular, of a uniform dark gray, and shows abundant small (up to 1 or 2 mm.) leucite phenocrysts, with very few of augite, in the dense aphanitic groundmass. The thin section shows rather abundant leucite phenocrysts, from 0.1 to 0.5 mm. in diameter, but no phenocrysts of augite or olivine, in a rather dark groundmass made up of minute augite prismoids in a darkish glassy base. There is little plagioclase.

The lava of the Bosco di Cognoli flow, as shown by specimens from the thick massive flow in Boscotrecase (Plate 8), contains, in the dark gray aphanitic groundmass, many phenocrysts of greenish black augite, and fewer of leucite. A specimen collected in June 1914 from near the main bocca (F, Plate 1) is similar, but the phenocrysts are somewhat larger and the groundmass darker, denser, and more vitreous. The lava of the easternmost bocca, from which came the flow that reached Terzigno, is almost aphyric, lighter gray, and with very few phenocrysts of augite and scarcely any of leucite.

The thin sections of the Bosco di Cognoli main flow collected at Boscotrecase show fewer but larger leucite phenocrysts than in the 1905 flows, with very abundant minute leucite crystals in the groundmass. There are some phenocrysts of rather greenish augite and a large thin plate or two of biotite is seen here and there. The groundmass is made up of the minute leucites with interstitial felt of minute augite prismoids, and considerable plagioclase (mostly bytownite) in small, thick tables. There is no olivine, no magnetite grains are to be seen, and the groundmass appears to be holocrystalline; it is certainly much less vitreous than that of the northwest flows.

The microtextural differences between the two types are essentially those between the aa and pahoehoe types of ordinary basalt, leucite at Vesuvius largely replacing plagioclase. As has been pointed out in a paper on the basalts of Hawaii,[1] the chief cause of the difference between the ropy, slow-moving, slightly steaming pahoehoe, with a highly vitreous texture, and the more massive, rapidly flowing, and densely steaming aa, with holocrystalline texture, is as follows: The pahoehoe magma, by simmering in the throat of the volcano, has lost a large part of the vapor in solution in it, and issues thus with little internal mobility and consequent high viscosity, so that it cools rapidly from the surface inward and the viscosity increases rapidly to the point at which crystallization is no longer possible and the lava solidifies as a whole very largely as glass. On the other hand, aa lava issues at a lower temperature than pahoehoe but very highly charged with gas, giving it great internal mobility, so that it flows en masse with high velocity and crystallization takes place very rapidly throughout and continues almost or quite to the point of complete solidification, the internal molecular mobility being maintained chiefly by the constant state of gas-saturation brought about by the continuous crystallization and the maintenance of a high temperature caused by the same process. The two very different types of vesiculation that are characteristic of aa and of pahoehoe are caused by the two different kinds of solidification.

It would appear that the two types of texture, microscopic and megascopic, with the inferences as to the conditions of the magma within the throat that have been drawn from them, harmonize well with Perret's views as to the mechanism of the eruption during its various phases. The 1905 northwest lavas were derived from the upper part of the long-standing column, which was continuously simmering and giving off gas, whereas the Bosco di Cognoli and the other southeast flows, of April 5–8, were derived from the deeper parts of the column and were composed of magma that issued highly charged with gas, hence highly mobile and capable of rapid and distant flow and complete crystallization in spite of the continuous movement. Without discussing here the subject in greater detail, it may be said that the microscopical study of the lavas of 1906 bears out Perret's views as to the general progress and mode of action of the eruption during its various phases.

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